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by
His Widow,
Mrs. Eliza Farrar,
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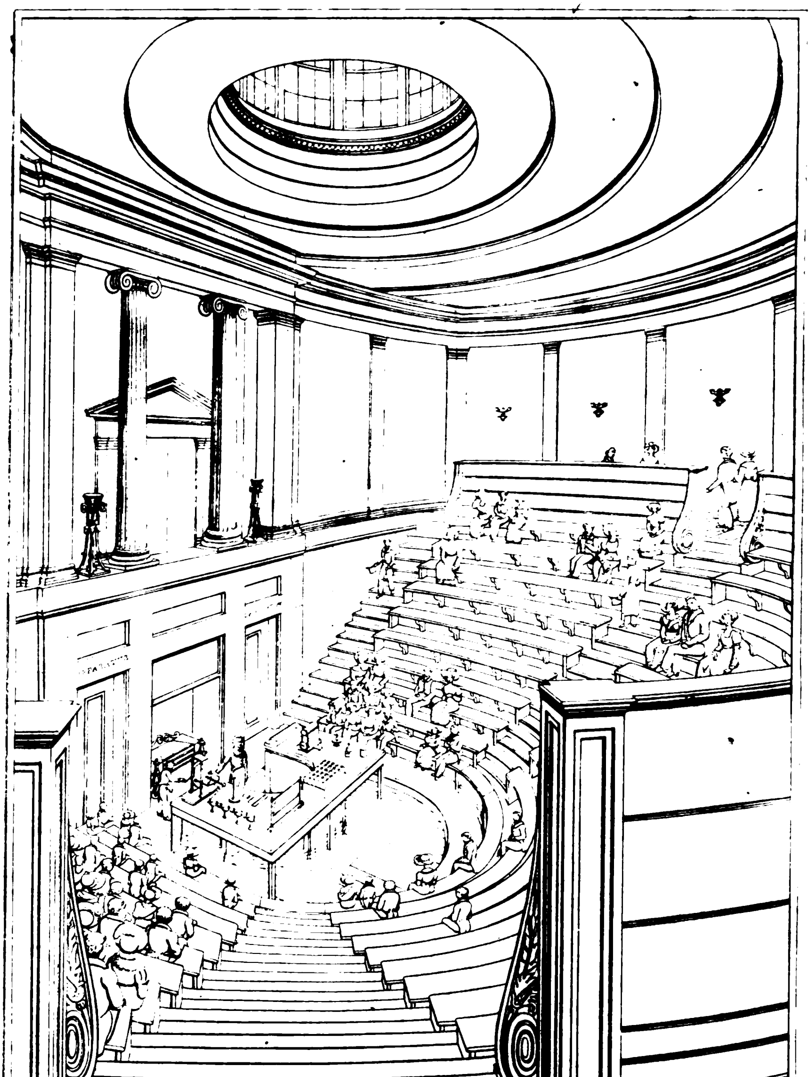

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MANUAL

OF

NATURAL AND EXPERIMENTAL PHILOSOPHY,

BEING THE SUBSTANCE OF

A SERIES OF LECTURES

DELIVERED IN THE

LONDON, RUSSELL, SURREY, AND METROPOLITAN INSTITUTIONS.

BY CHARLES F. PARTINGTON,

AUTHOR OF AN "HISTORICAL AND DESCRIPTIVE ACCOUNT OF THE STEAM-ENGINE,
"GALLERY OF SCIENCE," &c. &c.

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NATURE OF LIGHT, AND CONSTRUCTION OF OPTICAL MACHINES.

Hypothesis as to the Nature of Light.—Newton.—Huygens.—Materiality of Light.—Velocity and Minuteness of its Particles according to the latter Hypothesis.—Effects on Vegetation, and other Natural-Phenomena.—Reflection of Light.—Variously formed Mirrors.—Caleidoscope.—Nature of Reflection.—White Light a Compound of various Colours—Rays differ in Refrangibility.—Prism.—Spectrum.—Magnetizing Power of various Coloured Rays.—Calorific and Colorific Rays.—Rainbow.—Inflection.—Polarization of Light.—Construction of Lenses.—Improvements by Dr. Brewster.—Compound Burning Glass.—Nature of Vision.—Anatomy of the Eye.—Permanency of Objects on the Retina.—Defective Vision.—Long and Short Sight.

As all the phenomena which offer themselves to our observation in this science, owe their origin to the direct agency, or presence of light: it may be advisable, in the first place, to examine some of its more important properties; and then show the application of those data to the construction of optical machines.

There are two theories, or rather, hypotheses, that have been adopted to explain the action of light, with reference to its transmission. The one supposes the rays to consist of small particles, and, as such, material; while the other presumes the existence of a fluid pervading all space, which, by its vibratory motion, enables us to see luminous bodies. According to the latter hypothesis, light may be considered as analogous to sound, which is known to depend entirely on the pulsations of the air and other sonorous bodies transmitting a vibratory motion to the organs of hearing.

A very striking circumstance respecting the propagation of light, is the uniformity of its velocity in the same medium. According to the projectile hypothesis, the force employed in the free emission of light must be about a million million times as great as the force of gravity at the earth's surface; and it must either act with equal intensity on all the particles of light, or must impel some of them through a greater space than others, if its action be less powerful, since the velocity is the same in all cases: for example, if the projectile force is weaker with respect to red light than with respect to violet light, it must continue its action on the red rays to a greater distance than on the violet rays. There is no instance in nature, besides, of a simple projectile moving with a velocity uniform in all cases, whatever may be its cause; and it is extremely difficult to imagine that so immense a force of repulsion can reside in all substances capable of becoming luminous, so that the light of decaying wood, or of two pebbles rubbed together, may be projected precisely with the same velocity, as the light emitted by iron burning in oxygen-gas, or by the reservoir of liquid fire on the surface of the sun. Another cause would also naturally interfere with the uniformity of the velocity of light, if it consisted merely in the motion of projected corpuscles of matter: M. Laplace has calculated, that if any of the stars were 250 times as great in diameter as the sun, their attraction would be so strong as to destroy the whole momentum of the corpuscles of light proceeding from it, and to render the star invisible at a great distance; and, although there is no reason to imagine that any of the stars are actually of this magnitude, yet some of them are probably many times greater than our sun, and therefore large enough to produce such a retardation in the motion of its light, as would materially alter its effects.

If, however, we adopt the opinion, that the particles of light are material, and that they are continually passing from the various luminous bodies that surround us, it may be inquired why they do not interfere with each other in such a manner as to confound all distinct perception of objects, if not quite destroy the sense of seeing? Their velocity, however, enables us to answer these questions, by convincing us that they may be separated at least a thousand miles, and yet be perfectly efficient to the purposes of vision. It is an undoubted fact, that the effect of light upon the eye is not instantaneous, but that the impression remains after the light has been withdrawn. Of this, any one may satisfy himself, by shutting his eye, after having looked for some time on a candle, a star, or any other luminous object, when a faint momentary picture of the object will remain. The same thing may be proved by whirling round a stick, the extremity of which is on fire; if the motion be quick enough, the perception of a complete circle of flame will be impressed on the eye. The actual duration, for a certain time, of the impression of light being thus proved, let it be supposed to continue distinct only for the 150th part of a second; then, if one lucid point of the sun's surface emit 150 particles of light in a second, these will be amply sufficient to afford light to the eye without any intermission; and yet the particles emitted will be more than 1000 miles apart.

It has been ascertained by the astronomical observations of Roemer and of Bradley, that each ray of light emitted by the sun, arrives at the earth in eight minutes and one-eighth, when the earth is at its mean distance of about ninety-five millions of miles. Roemer deduced this velocity from observations on the eclipses of the satellites of Jupiter; and Bradley confirmed it by his discovery of the cause of the apparent aberration of the fixed stars.

But we have other proofs not less decisive than this, of the extreme minuteness of the particles of light, when we observe with what facility they penetrate the hardest bodies, as glass, crystal, precious stones, and even the diamond itself, through all which they find an easy passage, or those bodies could not be transparent. When a candle is lighted, if there is no obstacle to obstruct its rays, it will fill a space of two miles round with luminous particles in an instant of time, and before the least sensible part of the substance is lost by the luminous body. Nay, how small must the particles of light be, when they pass without removing the minutest particles of microscopic dust that lay in their way, and even these minute particles are rendered visible, by reflecting back the particles of light that strike against them.

Some bodies intercept light, or are opaque; others allow its transmission, and as such, are transparent; and there are gradations from perfect opacity to nearly perfect transparency. It is probable, that opacity results from the attraction of the substance for light, and not from its density: for it can scarcely be supposed that the particles of bodies should not be far enough distant to allow of the passage of light. Newton supposes the particles of transparent bodies to be of uniform density and arrangement, and attracting the ray of light equally in every direction, they suffer it to pass through them without obstruction; whereas, in opaque bodies, the particles are either of unequal density, or irregularly arranged, and the light being unequally attracted, cannot therefore penetrate the body.

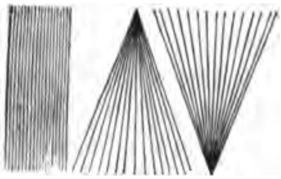
Experience has long ago established the fact, that vegetables become destitute of smell and colour, and lose much of their combustibility, by growing in the dark. In Dr. Black's Lectures, we find an illustration of this circumstance in an account given by the celebrated Dr. Robinson, of Edinburgh. In the drain of a coal-work under ground, he accidentally laid his hand upon a very luxuriant plant, with large indented foliage, and perfectly white. He had not seen any thing like it, nor could any one inform him what it was. He had the plant brought into the open air in the light. In a little time the leaves withered, and soon after new leaves began to spring up, of a green colour, and of a different shape from that of the old ones. On rubbing one of the leaves between his fingers, he found that it had the smell of common tansy, and ultimately it proved to be that plant, which had been so changed by growing in the dark. Indeed, it was recollected that some soil had been taken into the drain from a neighbouring garden, some time before it was found so altered.

This effect of light is not less conspicuous in the growth of celery. By covering it with earth, the light is shut out, which would very soon turn it green, and make its flavour so strong as to render it unfit to be eaten, at the same time that it would render it more fibrous and tenacious.

The parts of fish also, which are exposed to the light, such as the back, or fins, are uniformly coloured; but the belly, which is deprived of it, is white in nearly all of them; while birds that inhabit tropical countries have much brighter plumage than those of the North; and this is also the case with every species of insect.

Light is found to produce various chemical changes upon bodies. When the oxyd of silver is precipitated from nitric acid by muriatic acid, the insoluble muriate is at first white, and if kept in the dark at the common temperature, would doubtless remain so for an indefinite length of time. If, however, it be exposed to the light for a little time, it begins to assume a purple colour, and ultimately becomes black. This effect takes place more rapidly according to the intensity of the light. Hence, it has been proposed to measure the intensity of light by the time of its changing. An instrument has been invented for this purpose by Mr. Leslie.

It has been shown that rays of light diverge in every direction from the various luminous or radiant bodies that surround us. A pencil of rays emitted from a point are seen at one extremity of the subjoined diagram.



A series of parallel rays are placed at the opposite extremity, while the central rays are convergent; an effect which is easily produced by optical machines.

When a ray of light falls upon any polished surface, a portion is reflected; and the more obliquely it falls upon the surface of the body, the greater in general is the reflected portion. To ascertain the amount of divergence from the reflecting plane, it may be taken as an axiom, that the angle of reflection is invariably as the angle of incidence, and upon this circumstance all the properties of plane mirrors depend.*

The effect of combining two or more plain mirrors, so as to produce a multiplication of images, was known at a very early period, and described by writers on optics. Baptista Porta, in his "Magia Naturalis," gives an account of the construction of an instrument, which he calls a *polyphaton*, in which two rectangular specula are united by two of their sides, so that they may be opened or shut like a book, and the angles varied; and also of a polygonal speculum, consisting of several mirrors arranged in a polygon, for multiplying in different directions the images of objects. Kircher, also, in his "Ars Magna Lucis et Umbra," describes as an invention of his own, the former of these constructions, and distinctly traces the relation between the angle of inclination of the mirrors, and the number of images formed. The very same contrivance was afterwards adopted by Bradley, for the purpose of assisting in the designing of garden plots and fortifications; and he states that, "from the most trifling designs, we may, by this means, produce some thousands of good draughts." But the particular application of this principle, in the case where the two reflectors are inclined to one another at a small angle, so as to form a series of symmetrical images distinctly visible only in a particular position of the eye, was a discovery reserved for Dr. Brewster. The first idea of this remarkable property occurred to him in the course of some experiments in which he was engaged on the polarization of light, during the year 1814. But the only circumstance which at that time attracted his attention, was the circular arrangement of the images of a candle round the centre, and the multiplication of the sectors formed by the extremities of the plates of glass, between which the light had undergone several successive reflections. In repeating, at a subsequent period, some experiments of M. Biot, on the action of homogeneous fluids upon polarized light, and in extending them to other fluids which he had not tried, Dr. Brewster happened to place them in a triangular trough, formed of two plates of glass, cemented together by two of their sides, so as to form an acute angle. The ends being closed up with pieces of plate glass, cemented to the other plates, the trough was fixed horizontally, for the reception of the fluids. The eye being necessarily placed without the trough, and at one end, some of the cement, which had been pressed through between the plates, at the object end of the trough, appeared to be arranged in a remarkably regular and symmetrical manner. Pursuing the hint thus obtained, and investigating the subject optically, he discovered the leading principles of the caleidoscope, in as far as the inclination of the reflectors, the position of the object, and that of the eye, were concerned.

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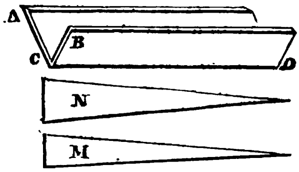
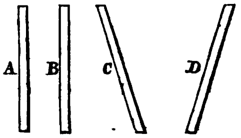
* By the *angle of incidence*, is meant the angle made by a ray of light, with a perpendicular to the reflecting surface, at the point where the ray falls; and by the *angle of reflection*, the angle which the ray makes with the same perpendicular on the other side.

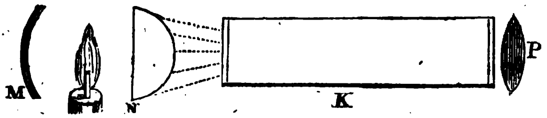
This instrument, in its most common form, consists of two reflecting surfaces, inclined to each other at any angle, but more properly at an angle which is an aliquot part of 360°. The reflecting surfaces may be two plates of glass, plain or quicksilvered, or two metallic surfaces, or the two inner surfaces of a solid prism of glass, or rock crystal, from which the light suffers total reflection. The plates should vary in length according to the focal distance of the eye; five, six, seven, eight, nine, and ten inches will in general be most convenient; or they may be made only one, two, three, or four inches long, provided distinct vision is obtained at one end, by placing at the other end an eyeglass, whose focal length is equal to the length of the reflecting planes. The inclination of the reflectors that is in general most pleasing, is 18°, 20°, or 22½°, or the 20th, 18th, and 16th part of a circle, but the planes may be set at any required angle, either by a metallic, a paper, or cloth joint, or any other simple contrivance. When the two planes are put together, with their straitest and smoothest edges in contact, they will have the form shown in the diagram A B C D, where A B C is the aperture, or angle formed by the plates. In this figure the plates are rectangular; but it may often be more convenient to give them the triangular form, shown at M or N. When the instrument is thus constructed, it may be either covered up with paper or leather, or placed in a cylindrical or any other tube, so that the aperture A B C may be left completely open, and also a small aperture at the angular point D. If the eye is now placed at D, and looks through the aperture A B C, it will perceive a brilliant circle of light, divided into as many sectors as the number of times that the angle of the reflectors is contained in 360°. If this angle is 18°, the number of sectors will be 20°; and, whatever be the form of the aperture A B C, the luminous space seen through the instrument will be a figure produced by the



arrangement of twenty of these apertures round C, as a centre, in consequence of the successive reflections between the polished surfaces. Hence it follows, that if any object, however ugly or irregular in itself, is placed before the aperture A B C, the part of it that can be seen through the aperture will be seen through every sector, and every image of the object will coalesce into a form mathematically symmetrical, and highly pleasing to the eye. If the object be put in motion, the combination of images will likewise be put in motion, and new forms, perfectly different, but equally symmetrical, will successively present themselves, sometimes vanishing in the centre, sometimes emerging from it, and sometimes playing around in double and opposite oscillations. When the object is tinged with different colours, the most beautiful tints are developed in succession, and the whole figure delights the eye by the perfection of its forms and the brilliancy of its colouring. The motion of the object may be effected either by the hand, or by a simple piece of mechanism; or the same effect may be produced by the motion of the instrument over the object, or round its own axis. In the form of the caleidoscope now described, the object should be held close to the aperture A B C, and the eye should be placed as nearly as possible in the line C D; for the figure loses its symmetry in proportion as the object recedes from A B C, and as the eye rises above D. The instrument is therefore limited, in its present form, to the use of objects which can be held close to the aperture. In order to remove the limitation, the tube which contains the reflectors should slide in another tube, of nearly the same length, and having a convex lens at its farther extremity; the focal length of the lens should be always less than its greatest distance from the aperture A B C. In general, it should be about one-third or one-fourth of that distance, but it will be advisable to have two or even three lenses of different focal lengths, to fit into the end of the outer tube, and to be used as circumstances may require, or a variation of focal length may be produced by the separation or approach of two lenses. When the instrument is thus fitted up, it may be applied to objects at all distances; and these objects, whose images are formed in an inverted position at the aperture A B C, may be introduced into the symmetrical picture in the very same manner as if they were brought close to the instrument. Hence we can introduce trees, flowers, statues, and living animals; and any object which is too large to be comprehended by the aperture A B C, may be removed to such a distance that its image is sufficiently reduced. The caleidoscope is also constructed with three or more reflecting planes, which may be arranged in various ways. The tints placed before the aperture may be the complimentary colours produced by transmitting polarized light through regularly crystallized bodies, or pieces of glass that have received the polarizing structure. The partial polarization of the light, by successive reflections, occasions a partial analysis of the transmitted light; but in order to develope the tints with brilliancy, the analysis of the light must precede its admission into the aperture. Instead of looking through the extremity D of the tube, the effects which have been described may be exhibited to many persons at once, upon the principle of the solar microsoope, or magic-lantern; and, in this way, or by the application of the camera-lucida, the figures may be accurately delineated. When the instrument is thus applied to the purposes of the arts, an infinity of patterns is created, and the artist can select such as he considers most suitable to his work. When a knowledge of the nature and powers of the instrument has been acquired, by a little practice he will be able to give any character to the pattern that he chooses, and he may even create a series of different patterns, all rising out of one another, and returning, by similar gradations, to the first pattern of the series. In all these cases, the pattern is perfectly symmetrical round a centre, or all the images of the aperture A B C are exactly alike: but this symmetry may be altered; for, after the pattern is drawn, it may be reduced into a square, a triangular, an elliptical, or any other form that he pleases. The instrument will give annular patterns, by keeping the reflectors separate, as at C D; and it will give rectilineal ones, by placing the reflectors parallel to each other, as in A B.

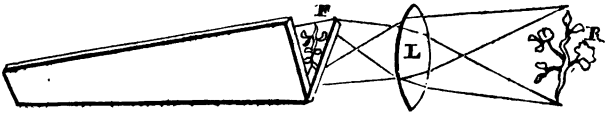


The exhibition of the effects of the caleidoscope to a number of spectators at the same time, by throwing the images on a wall, after the manner of the magic-lantern, or solar microscope, might be easily accomplished, if sufficient light could be procured for the illumination of the objects. The form of an instrument for this purpose, is represented in the accompanying figure, where a powerful



flame or lamp is employed: the light from which being augmented by the reflector M, and concentrated by the very convex lens N, upon the transparent objects at the end of the caleidoscope K, is formed into an image on the opposite wall by refraction through the lens P, the focal distance of which is somewhat shorter than the length of the tube. The brilliant light produced during the combustion carried on by means of a stream of oxygen gas, is peculiarly fitted for the exhibition of these effects.

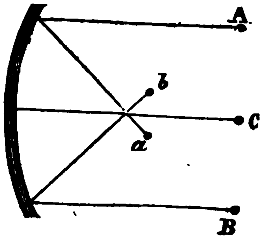
Dr. Brewster has furnished us with a very pleasing variety of this instrument in the *telescopic caleidoscope.* It consists in substituting the images of distant objects for the small transparent bodies usually employed, which is effected by placing a convex lens at a certain distance from the tube. The arrangement of the apparatus will readily be understood, as the theory of its construction has already been described.



The lens L forms an image of the object R at F, which image is multiplied by the reflecting powers of the instrument, and forms a symmetric spectrum, precisely in the same way as if a real object of that size had occupied its place. The lens may be fitted to the end of a separate tube, external to that of the instrument, and capable of being drawn out upon it to the proper distance, which is known by observing when the spectrum appears perfectly symmetrical. The instrument in this form has been called the *telescopic* or *compound caleidoscope;* and is applicable to distant objects of every description, and equally so to those in motion as those at rest. All their movements are represented with singular effect in the spectrum. A blazing fire viewed by it, gives the appearance of beautiful fire-works, at one time rushing with great rapidity towards the centre, and at another, issuing from it towards the circumference, or darting in splendid starriform corruscations over the field of vision. These varieties in the spectrum are occasioned both by turning the instrument round its axis, and by moving it forwards in any direction. The compound caleidoscope has thus a much more extended range than the simple kind; and it has this further advantage, that it admits of the symmetry of the spectrum being rendered perfectly correct, since the images may be brought exactly to the ends of the mirrors; a condition which never can be completely obtained, when the objects are confined in a glass case, as they must then always be separated from the mirrors, by at least the thickness of the glass. The focal length of the lens should always be much less than the length of the outer tube, and should in general be such as to be capable of forming an image at the end of the mirrors, when the object is four or five inches from the lens. Its diameter should be such as that, when it is at its greatest distance from the mirrors, it shall still occupy the whole of the field of view which is seen by direct vision; or, in other words, that the eye shall not see any part of its edge.

The effects which result from the falling of parallel rays of light on a concave mirror, will be easily understood by reference to the opposite figure.

The ray A, on striking against the glass, is reflected back towards *a*; while B, is similarly reflected towards *b*. The ray C, on the contrary, returns back precisely in the same direction as it had previously descended. In the above figure, we have only represented three rays, but it will be obvious, that rays of light will fall on every part of the polished surface, and, as such, form a distinat picture of the image to be reflected. The rays are also inverted,



as will be seen by reference to the change that occurs in the position of the letters.

There are, however, other phenomena connected with the operation of concave mirrors. By them, convergent rays are rendered more convergent; their effect, therefore, is to magnify. This effect, however, will only take place when the eye is between the mirror and its principal focus, that is, the focus or point where rays falling parallel or perpendicular on the glass, will unite after reflection; the point where the rays of the sun, which are always considered as parallel, will unite and burn, for a concave mirror acts as a burning glass. By the ordinary law of reflection, the principal focus of a concave mirror is at one-half of the diameter of that sphere, of which the concave surface is a section, which is therefore sometimes called the centre of concavity.* At this point, the rays reflected from the mirror are converged and cross; and if the spectator's eye is beyond this point or focus, he will not see the image behind the mirror, but before it, a shadowy form suspended in the air, but from the crossing of the rays it appears inverted.

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* To find the focal distance of a concave mirror, place it so that its axis may be directed to the centre of the sun. Find the burning point, or receive the image upon a white piece of paper, and the distance thus found, between the paper and the centre of the speculum, is the focal length. Or, cover the mirror with paper, in which make two or more holes, and observe where the beams of light reflected from these holes unite, and this will be the focal distance.

If a person be placed directly before a large concave mirror, but further from it than its centre of concavity, he will see an inverted image of himself in the air, between him and the mirror, of a less size than his own person. If he hold out his hand towards the mirror, the hand of the image will come out towards his hand, and coincide with it, of an equal bulk when his hand is in the centre of concavity; and he will imagine he may shake hands with his image. If he reach his hand further, the hand of the image will pass by his hand, and come between it and his body; and if he move his hand towards either side, the hand of the image will move towards the other; so that whatever way the object moves, the image will move the contrary way. A by-stander will see nothing of the image, because none of the reflected rays that form it enter his eyes. From this remarkable property of a concave mirror to form an image in the air, mirrors of this sort are used to produce a variety of singular appearances, to amuse the curious, or to impose upon the ignorant and superstitious. A few of these experiments may be noticed.—If a fire be made in a large room, and a smooth mahogany table be placed at a considerable distance near the wall, before a large concave mirror, so situated that the light of the fire may be reflected from the mirror to its focus upon the table, and a person stand by the table, he will see nothing upon it but a long beam of light; but if he advance towards the fire, not directly between the fire and the mirror, he will see an image of the fire upon the table, large and erect. If another person, who knows nothing of the experiment beforehand, should chance to enter the room, and look from the fire towards the table, he would be startled at the appearance; for the table would seem to be on fire. In this experiment, there should be no light in the room but what proceeds from the fire; and the mirror ought to be at least fifteen inches in diameter. If the fire used in the last experiment be extinguished, or covered by a screen, and a large candle be placed in a similar position, a person standing by the candle, will see the appearance of a star, or rather planet, upon the table, as brilliant as Venus or Jupiter in a cloudless sky; and if a slender wax-taper be then placed near the candle, a satellite to the planet will appear on the table; and on moving the taper round the candle, the mimic satellite will go round the planet. Another experiment may be adduced:—take a glass bottle, partly fill it with water, and cork it in the common manner: place this bottle opposite a concave mirror, and beyond its centre of concavity, that it may appear reversed; let the spectator retire to a still greater distance than the bottle, which he will then see in the air inverted, and the water, which is actually in the lower part of the bottle, will in the image appear uppermost. Invert the bottle whilst before the mirror, and in the image the water will appear in the lower part of the bottle; when it is in this inverted state, uncork the bottle, and whilst the water is running out, the image will appear to be filling; but as soon as the bottle is empty, the illusion ceases. As the image formed by a concave mirror may be thrown through a hole into an adjoining room, where a spectator will in certain situations perceive the image of any object the concealed manager may choose, it is evident how much the credulous may be imposed upon.*

From what we have seen of the optical effects of a bent glass, it will be evident that an object of a certain size, placed either perpendicularly or obliquely before a convex mirror, will necessarily appear curved or bent, because the different points of the object are not at equal distances from the surface of the mirror. All these effects will be very apparent from inspecting one of the small glass globes, lined with common amalgam used for making looking-glasses; which are sometimes suspended in old-fashioned apartments. In these, the company seated in the room, or round the table, are represented by very minute images, which appear not at a certain distance behind, as in plain looking-glasses, but very near the surface of the mirror, and always in some degree curved or distorted.

Mirrors are sometimes constructed for optical purposes, which combine the effects of plain and spherical glasses. The properties of cylindrical mirrors are such that the dimension of objects, corresponding lengthwise to the mirror, are not much changed; but those corresponding breadthwise, have their figure altered, and their dimensions lessened, the further they are from the mirror, whence arises a very great distortion. 2. If the plane of the reflection cut the cylindrical mirror through the axis, the reflection is

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A few years back, a person derived considerable emolument from exhibiting in the metropolis some optical deceptions of this kind with concave mirrors. A ghastly apparition was sometimes made to meet the uninitiated spectator, and from its shadowy appearance, was viewed as something superhuman. At other times, a hand was held out in the air with every possible mark of friendship, but when he approached to unite it with his own, a drawn sword was instantly presented to his breast. A nosegay, or a piece of fruit was offered, but when the spectator attempted to seize it, a death's head appeared.

performed in the same manner as in a plane mirror; and if parallel to the base, the reflection is the same as in a spherical mirror; if it cut it obliquely, the reflection is the same as in an elliptic mirror. Hence, as the plane of reflection never passes through the axis of the mirror, except when the eye and the object are in the same place; nor parallel to the base, except when the radiant point and the eye are at the same height; the reflection is therefore usually the same as in an elliptic one. If a hollow cylindric mirror be directly opposed to the sun, instead of a focus of a point, the rays will be reflected into a lucid line parallel to its axis, at the distance of about one-fourth of its diameter. Conical mirrors produce a still more extraordinary distortion of the figures seen in them, than cylindrical ones, from the breadth of the image being gradually reduced as it approaches the apex, where it becomes a mere point.

The effect of a cylindrical mirror in diminishing the breadth of objects facing it, being the same as that of a convex mirror of the same radius, and the effect of the conical mirror, at any given height, being regulated by the same principle, it becomes easy to draw anamorphoses for a cylindrical or conical mirror of any size. The pictures called by this name, and which are sold with mixed mirrors by the opticians, appear very much distorted, but when placed before the mixed mirror for which they are intended, their images are well calculated for ordinary vision.

We must not omit to notice some burning mirrors, which were celebrated on account of their size and extraordinary effects. One of these optical machines was the work of Stettala, a canon of Milan; it was parabolic, and, acting as a burning glass, inflamed wood at the distance of fifteen or sixteen paces. Vilette, an artist and optician of Lyons, constructed three, about the year 1670; one of which was presented to the king of Persia; the second was purchased by the king of Denmark; and the third by the king of France. The one last mentioned was thirty inches in diameter, and of about three feet focus. The rays of the sun were collected by it into the space of about one inch. It immediately set fire to the greenest wood: it fused silver and copper in a few seconds; and in one minute vitrified brick and flint earth. A mirror superior even to these was constructed by Baron Von Tchivnhausen, about 1687; it consisted of a metal plate, twice as thick as the blade of a common knife; it was five feet three inches in breadth, and its focal distance was three feet six inches; it produced the following effects: wood, exposed to its focus, immediately took fire; copper and silver passed into fusion in a few minutes, and slate was transformed into a kind of black glass, which, when laid hold of with a pair of pincers, could be drawn out into filaments. Pumice stone and fragments of crucibles, which had withstood the most violent furnaces, were also vitrified.*

Besides the properties of light to be reflected and transmitted, there are some curious phenomena, arising from the attraction of light. When a ray of light enters any transparent medium, in a direction perpendicular to its surface, the ray will maintain its course in the same direction; but if the ray of light make any angle less than a right angle with the surface of the medium, it will not continue in the same direction, but will be drawn towards a straight line, perpendicular to the same surface, and passing through the medium at the point where the oblique ray enters. The angle which the incident ray makes with the perpendicular, is called the angle of incidence; and the angle which the ray makes with the same perpendicular, after it enters the medium, is called the angle of refraction. In all the degrees of obliquity at which a ray enters any medium, the sine of the angle of incidence has the same ratio to the sine of the angle of refraction.

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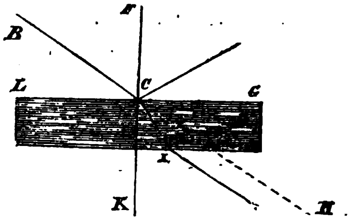
* Burning-mirrors may be constructed of various other materials as well as metal; and when formed of wood and leaf gold, nothing is necessary but to turn a piece of exceedingly dry and very hard wood into the form of the segment of a concave sphere; to cover it in an uniform manner with a mixture of pitch and wax, and then apply bits of gold-leaf, about three or four inches in breadth. Instead of gold leaf, small plane mirrors might be adapted to the concavity, and the effect would be little inferior to that of a mirror made entirely of metal. Father John mentions a mirror made of pasteboard, covered on the inside with straw cemented to it, which was so powerful as to fuse all metals.



The ray, in the first instance, descends from B to C, and enters the flat plate of glass, which, giving a new direction, causes it to approach the perpendicular. The original angular path, however, is again resumed on arriving at I, though it will be obvious, that if the glass had not intervened, it would have continued in the direction of B H. If we suppose another ray to fall perpendicularly on a similar plane of glass, as F K on L G, that ray will continue its course without being bent out of its ordinary direction.*

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* This principle will explain several of the common phenomena of nature. Mr. Walker observes, that "many a schoolboy has lost his life, by supposing the bottom of a clear river to be within his depth,

Bodies differ very materially in their refractive power, and we may here introduce a table, forming a sufficiently numerous series for illustrating their properties in this respect: the connexion between their combustibility and refractive power will be apparent.

Hydrogen	6.61436
Diamond	3.1961
Olive Oil	2.7684
Alcohol	2.2223
Ammonia	2.16851
Carburetted Hydrogen	2.09270
Gum Arabic	1.8826
Water	1 7225
Muriatic Ether, in gaseous state	1.71344
Muriatic Acid Gas	1.19625
Nitrogen	1.03408
Carbonic Acid	1.00476
Atmospheric Air	1.00000
Oxygen	0.86161

as (when he stands on the bank) the bottom will appear one-fourth nearer the surface than it really is." The skilful marksman who shoots a fish in the water with a bullet, takes his aim considerably below the fish as it appears, because it appears much nearer the top of the water than it really is. As the refraction in all cases must depend on the obliquity of the ray, that part of any body which is most immersed, will seem to be most materially altered by the refraction. When, however, the object extends to no great depth in the water, the figure is not materially distorted; but if the object is of a considerable size, or extends to a great depth, those rays which proceed from the more distant extremities come in a more oblique direction on their emergence into the air, and, consequently, they suffer a greater refraction than the rest. Thus, a straight leaden pipe appears near the bottom of a deep water to be curved, and a flat bason seems deeper in the middle than near the sides.

The refraction of light may be thus illustrated, without the aid of

By a reference to the preceding table, it will be found that inflammable bodies refract light much more than those that are not inflammable. Sir Isaac Newton divided transparent bodies into two classes, each of which had the power of refracting light. The first consisted of the inflammable, in which it was much more than according to the ratio of their density.

The other class, which were not inflammable, appeared to obey the same law as to density, with the exception of the diamond, and water. The former of these refracted in the compound ratio of inflammability and density; and although it was then not known to be inflammable, Newton strongly suspected it to be entirely an inflammable body; and water, which appeared to have an intermediate power between the two classes, he supposed, was partly inflammable. These prophetic observations have been verified, in the discovery of the diamond being pure carbon, and in the decomposition of water.

Prior to a more minute examination of the nature of atmospheric refraction, it may be advisable to illustrate its effects by a simple figure.

The central circle, representing the earth, is surrounded by a boundary line of air. A person placed at *p*, is viewing the sun, or any other heavenly body at *r*, although it is not really above the plane of the horizon *h o*. This ap-

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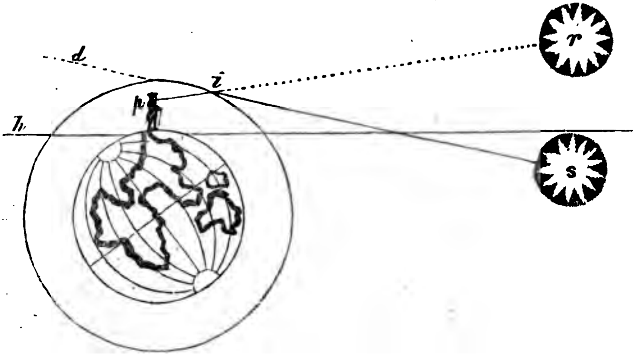
apparatus. Take an empty bason into a dark room, make a small hole in the window shutter, so that a ray of light may proceed to the bottom at a given point: mark the spot: then, without disturbing the bason, pour water into it, and the ray, instead of proceeding to the point marked, will be bent out of its first direction, and be found at another point nearer the side. In repeating the experiment, if a piece of looking-glass be laid at the bottom of the bason, the light will be reflected from it, and will be observed to suffer the same kind and degree of refraction in going out, as in coming in, only in a contrary direction.

parently paradoxical phenomenon is the result of refraction, for the rays of light are bent out of their course on entering our atmosphere, and, as such, change the apparent position of the body.



The quantity of terrestrial refraction was estimated by Dr. Maskelyne at one-tenth of the distance of the object observed, expressed in degrees of a great circle. Henec, if the distance be 10,000 fathoms, its tenth part, 1000 fathoms, is the 60th part of a degree, or one minute, which, therefore, is the refraction in altitude of the object at that distance. But Le Gendre was induced, by a variety of experiments, to allow only one-fourteenth part of the distance for the refraction in the altitude; so that in the distance of 10,000 fathoms, the 14th part of which is 714 fathoms, he allows only 44″ of terrestrial refraction, so many being contained in 714 fathoms. Again, Delambre makes the quantity of terrestrial refraction to be one-seventh part of the arc of distance. And the English measurers, from many very exact observations, determine the quantity of the medium refraction to be a twelfth part of the said distance. The mean of all these is about .085 of the intercepted arc, which is probably not very far from the truth: this quantity, however, it must be observed, is found to vary very considerably with the different states of the weather and atmosphere, from one-seventh to one-eighteenth of the contained arc.

Picard found by meridian altitudes of the sun, in 1669, that it was greater in winter than in summer. He found, also, that it was less by day than by night. In the observations given at the end of his journey to Uraniburg, to settle the latitude of that place, and its difference of longitude from Paris, for the purpose of comparing the observations of Tycho Brahe with those made at the Royal Observatory at Paris, he found the horizontal refraction for the first limb of the sun that made its appearance above the horizon there 33′.2″, and for the second 32′.37″. So that in the small interval of time that the sun was in rising, the refraction was diminished twenty-five seconds by the warmth arising from the sun's presence.

It was soon found that the refraction near the pole must be greater than in our climate, the degree of cold being more intense. It was also found to be less in the torrid zone, where the heat is greater than in Europe. Bouguer made a variety of observations at Peru, the result of which he has given us. In 1740, he came down into an island situated in the river of Emeralds, called Isle of Inca, where he determined the refraction from 1_0 to 7° of altitude; and the table which he afterwards computed, shows the refraction to be about one-seventh less than in Europe. The horizontal refraction he found to be 27′; but at 6° of altitude it is 7′.4″; and at 45°, it is 44″. Bouguer then gives a table for Quito, which is more elevated above the level of the sea. M. le Gentil found it greater at Pondicherry in India, although in the torrid zone.

The most singular of all the phenomena of refraction is, perhaps, the property of some natural substances, which have a double effect on the light transmitted through them; as if two mediums of different densities freely pervaded each other, the one only acting on some of the rays of light, the other on the remaining portion. These substances are usually crystallized stones, and their refractions have sometimes no further peculiarity; but the rhomboidal crystals of calcareous spar, commonly called *Iceland crystal*, possess the remarkable property of separating such pencils of light, as fall perpendicularly on them, into two parts, one of them only being transmitted in the usual manner, the other being deflected towards the greater angle of the crystal. It appears from the experiments of Huygens, confirmed and extended by Dr. Wollaston, that the medium which causes the unusual refraction, has a different refractive power, according to the direction in which the light passes through it; and that if an oblate or flattened spheroid be described within a circle, its axis being in the middle of one of the obtuse solid angles, and its principal diameters in the proportion of 9 to 10, the refractive power, with respect to light passing in any direction, will always be inversely as the diameter of the spheroid which is parallel to it; and where it is greatest, will be equal to that of the medium which produces the usual refraction, of which the index is *. A ray of light falling perpendicularly on any surface of the spar, its point of incidence being considered as the centre of the spheroid, will meet the surface of the spheroid at the point where it is parallel to that of the spar; and a ray incident on the same surface in any other direction, will preserve a relation to the perpendicular ray, which is nearly the same as in ordinary refraction.

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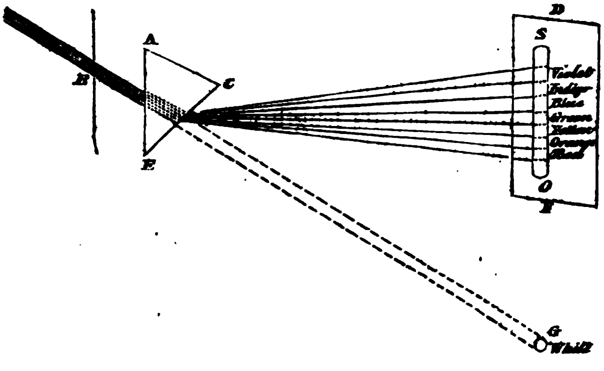
* The means of ascertaining the double refraction of substances are very simple; the following is quoted by M. Soret: "Two plates of tourmaline, cut parallel to the axis of the crystal, and placed crossways, so as to absorb all the light from the apparatus: the substance to be examined is to be placed within the plates; if it is doubly refractive, the light re-appears through the tourmalines; if not, all remains dark."

These phenomena will, however, be more fully examined under the article polarization.

We have hitherto considered the rays of light as perfectly homogeneous; but Newton discovered at a very early period of his investigations, that what we call white light, is, in reality, a compound of various-coloured rays differing in their refractive power. To experimentally illustrate this fact, it is only necessary to throw the ordinary sunbeam on a glass prism, and it will be found, that, instead of proceeding in its ordinary course, the ray will be decomposed, and show a coloured spectrum.

Newton thus describes his mode of performing this experiment, with reference to an engraved figure.



"In a very dark chamber, at a round hole B, about one-third of an inch broad, made in the shut of a window, I placed a glass prism A C E, whereby the beam of the sun's light B G, which came in at that hole, might be refracted upwards, towards the opposite wall of the chamber, and there form a coloured image of the sun, represented at S O. The axis of the prism (that is, the line passing through the middle of the prism, from one end of it to the other end, parallel to the edge of the refracting angle,) was in this, and the following experiments, perpendicular to the incident rays. About this axis I turned the prism slowly, and saw the refracted light on the wall, or coloured image of the sun, first to descend, and then to ascend. Between the descent and ascent, when the image seemed stationary, I stopped the prism and fixed it in that posture.

"Then I let the refracted light fall perpendicularly upon a sheet of white paper D F, placed at the opposite wall of the chamber, and observed the figure and dimensions of the solar image S O, formed on the paper by that light. This image was oblong, and not oval, but terminated by two rectilinear and parallel sides, and two semicircular ends. On its sides it was bounded pretty distinctly; but on its ends very confusedly and indistinctly, the light there decaying and vanishing by degrees. At the distance of 18½ feet from the prism, the breadth of the image was about 2⅛ inches, but its length was about 10¼ inches, and the length of its rectilinear sides about 8 inches; and the refracting angle of the prism, whereby so great a length was made, was 64 degrees.' With a less angle, the length of the image was less, the breadth remaining the same. It is farther to be observed, that the rays went on in straight lines from the prism to the image, and, therefore, at their going out of the prism, had all that inclination to one another, from which the length of the image proceeded. This image S O was coloured, and the more eminent colours red, orange, yellow, green, blue, indigo, violet, together with all their intermediate degrees, in a continual succession, perpetually varying."

The philosopher continued his experiments; and by making the rays thus decompounded pass through a second prism, he states, though erroneously, that they did not admit of farther decomposition, and that objects placed in the rays producing one colour, always appeared to be of that colour. He then examined the ratio between the sines of incidence and refraction of these decompounded rays, and found that each of the seven primary colour-making rays, as they may be called, had certain limits within which they were confined. Thus, let the sine of incidence in glass be divided into fifty equal parts; the sine of refraction into air of the least and most refrangible rays, will contain respectively 77 and 78 such parts. The sines of refraction of all the degrees of red will have the intermediate degrees of magnitude, from 77 to $77\frac{1}{3}$; orange from $77\frac{1}{3}$ to $77\frac{1}{2}$; yellow from $77\frac{1}{5}$ to $77\frac{1}{3}$; green from $77\frac{1}{3}$ to $77\frac{1}{2}$; blue from $77\frac{2}{3}$ to $77\frac{1}{2}$; indigo from $77\frac{2}{3}$ to $77\frac{7}{9}$; and violet from $77\frac{1}{2}$ to 78.

From this small number of simple sensations, then, with their combinations, we obtain seven primitive distinctions of colours: but the different proportions in which they may be combined, afford a variety of tints beyond all calculation. If we suppose three simple sensations, consisting of red, green, and violet, the three binary combinations are yellow, consisting of red and green; crimson, of red and violet; and blue, of green and violet; and the seventh in order, is white light, composed by all the three united. But the blue thus produced, by combining the whole of the green and violet rays, is not the blue of the spectrum, for four parts of green and one of violet make a blue, differing very little from green; while the blue of the spectrum appears to contain as much violet as green: and it is for this reason that red and blue usually make a purple, deriving its hue from the predominance of the violet.

The scientific world is indebted to Mr. Kent for a very curious series of experiments, tending to illustrate the analysis of white light. They go to prove that the solar beam may be reduced into three primary colours. Mr. Kent thus describes his experiments.

I threw the colours of the prism on a screen, eleven feet distant, and having placed the lens between them, and only two inches from the prism, I found the prismatic colours magnified, and in the same order, to the extent of two feet six inches in width, and one foot three inches in depth. In this case, the sun's rays were admitted through a Venetian blind; but when admitted through a hole in a shutter, of five inches by four, the dimension was only two feet by nine inches.

Having placed the lens at the focal distance of two feet three inches from the prism, the figure of the prism was clearly defined, without exhibiting any prismatic colours whatever on the screen.

I placed the lens three feet from the prism, which produced only the figure of the prism, having the violet ray at the bottom, and the yellow above.

When the lens was five feet from the prism, the figure of it was distinctly seen with the prismatic colours reversed.

I placed the lens behind the prism, and threw the sun's rays on it at its focal distance, two feet three inches, when the prismatic colours were increased, both in brilliancy and magnitude, considerably more than in the first experiment.

I put the lens within the focal distance of the screen, when a small figure of the prism was seen very bright, but without any prismatic colour.

Having placed the lens as in the second experiment, when no prismatic rays were produced, but a perfect spectrum of the prism in a strong white light; I then placed another prism in the focus of the lens, and to my surprise it produced three colours only: viz. yellow of a greenish tint, red, and deep violet. Wishing to ascertain if those three colours were neutral, I tried them with a third prism, and found not the slightest alteration; and having placed a card so as to receive them, I found, on giving it a whirling motion, that the colours were entirely lost.*

If by means of two prisms, a small piece of paper be illuminated, the one half with red, and the other half with violet light, and an observer view the same through another prism, the paper will, by the different refrangibility of the rays, appear divided into two. For the violet half being seen by a more refrangible light, will appear to be carried farther from its true place than the red, and will, therefore, seem to be separated from it. The same is likewise true of colours which arise from the separation of light, which is made by bodies on which it falls, and which we are apt to call natural colours; for if a paper be painted, the one half with a lively red, and the other half with an indigo, and it be placed in the sun's light, it will in the same manner appear divided, if viewed through a prism.

From what has been stated, the principal phenomena of colours may, without much difficulty, be explained. If all the different-coloured rays which the prism affords are reunited in the focus of a convex lens, the produce will be white; yet these same rays, which, taken together, form white, give, after the point of their re-union, that is, beyond the point where they cross each other, the same colours as those which departed from the prism, but in a reversed order, by the crossing of the rays; the reason of which is clear; for the ray being white before it was divided by the prism, must necessarily become so by the re-union of its parts, which the difference of refrangibility had separated, and this re-union cannot in any manner tend to alter or destroy the nature of the colours; it follows, then, that they must appear again beyond the point of crossing. A similar effect will be produced if the dispersed rays are received from the prism upon a concave reflector. In the focus of the reflector, they will unite and form a white or colourless image of the sun. But it is curious to remark, that if any one of the colours is stopped in its progress to the reflector by the interposition of a wire, or any other slender opake body, then the image in the focus will be an imperfect white, or a mixed colour. Beyond the focus, the rays separate again, as in the case of their passing through a convex lens, and form the coloured spectrum; only the order of the colours, from the crossing of the rays, is inverted.

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* Mr. Kent says, that the prism he used in his experiments, was five inches long, and the side planes one inch broad; the lens being six inches in diameter, with a focus of two feet three inches.

Having thus, by analysis, shown that white light may be decomposed, or reduced to what may at present be considered as its primary elements, it may now be advisable to show how its re-union may be effected, and we shall thus synthetically illustrate its nature. This is usually accomplished by whirling colours in the proportions already described, painted on a small disc of card, by means of a pin thrust through the centre. The same effect may, however, be more readily produced by painting on the surface of a board, the various tints being exactly neutralised by actual experiment, and attaching the screen to the axis of a whirling table. If this plan be resorted to, the most vivid tints may be blended, and a perfectly white ground produced.*

It was originally remarked by Newton, and the fact has since been confirmed by the experiments of Dr. Herschel, that the different-coloured rays have not the same illuminating power. The violet rays appear to have the least luminous effect: the indigo more; and the effect increases in the order of the colours, the green being very great; between the green and the yellow the greatest of all; the yellow the same as the green, but the red less than the yellow.

When the solar rays are passed through a convex lens, or reflected from a concave, a very intense heat is produced by the concentration of the rays. Count Rumford has shown, that when the rays of the sun are made to pass through a certain aperture, and fall upon any substance to be heated, while the same area of light is made to pass through a lens, in the focus of which the same quantity of matter is to be heated, they become heated in the same time to the same degree. Nothing is better known, in short, than that the rays of the sun are capable of exciting sensible heat. Newton, and the philosophers of his age, accounted for heat by the motion excited in the parts of the body by the agitating power of the absorbed light. Melville supposed that the heat was expelled from the terrestrial matter by the light. At present, it is generally admitted, on the strength of some valuable experiments to which we have already alluded, that the rays of light and caloric are separately emitted from the sun, the luminous rays producing light, and the caloric, heat.

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* If the whole spectrum be divided into 360 equal parts, the red will occupy 45 of them, the orange 27, the yellow 48, the green 60, the blue 60, the indigo 40, and the violet 80.

Sir William Herschel introduced a beam of light into a dark room, which was decomposed by a prism, and then exposed a very sensible thermometer to all the rays, in succession, and observed the heights to which it rose in a given time. He thus determined, that the heating power of the red, to that of the green rays, was 2¾ to 1; and 3½ to 1, in red to violet.

On repeating these experiments, he found that the greatest quantity of calorific rays were even beyond the coloured spectrum at about half an inch from the commencement of the red rays. At a greater distance from this point, it began to diminish, but was very perceptible even at the distance of 1½ inch.

It will appear, from what has been stated, that these calorific rays are less refrangible than the rays of light; hence the calorific focus will fall beyond that of the luminous. Dr. Herschel made an experiment to verify this inference, but did not come at any thing conclusive. He afterwards made experiments to collect these invisible calorific rays, and caused them to act independently of the light; by which he concludes, that they are sufficient to account for all the effects produced by the solar rays in exciting heat; that they are capable of passing through glass, and of being refracted and reflected, after they have been finally detached from the solar beam.

Dr. Morichini appears to have been the first person to point out the connection between *light and magnetism*. To experimentally illustrate this important fact, he employed a prism, and caused the decomposed rays to fall on a series of small needles, and the needle intersected by the violet ray was soon found to acquire permanent polarity. It has since been ascertained, that this property is not peculiar to the violet ray, but extends, though in a less degree, through several other rays in the series.

The phenomena arising from *atmospheric refraction* may be best understood by an examination of the apparent alteration in the colours of the heavens.

If the light of the setting-sun, by passing through a long tract of air, be divested of a portion of its rays, the remainder which is transmitted, will illuminate the western clouds with an orange colour, and as the sun sets more and more, a greater number are reflected, while the clouds grow more deeply red, till at length the entire disappearance of the sun leaves them of a leaden hue.

When a direct spectrum is thrown on colours darker than itself, it mixes with them; as the yellow spectrum of the setting sun, thrown on the green grass, becomes a greener yellow. But when a direct spectrum is thrown on colours brighter than itself, it becomes instantly changed into the reverse spectrum, which mixes with those brighter colours. So the yellow spectrum of the setting sun thrown on the luminous sky, becomes blue, and changes with the colour or brightness of the clouds on which it appears. But the reverse spectrum mixes with every kind of colour on which it is thrown, whether brighter than itself, or not: thus, the reverse spectrum, obtained by viewing a piece of yellow silk, when thrown on white paper, was a lucid blue-green; when thrown on black Turkey leather, becomes a deep violet: and the spectrum of blue silk, thrown on white paper, was a light yellow; on black silk, was an obscure orange; and the blue spectrum obtained from orange-coloured silk, thrown on yellow, became a green.

Of the natural phenomena produced occasionally by the separation of the primary colours, the *rainbow* is one of the most beautiful. This meteor, which in poetical language is called the *iris*, never makes its appearance, except when the spectator is situated between the sun and a shower of rain; and that this conclusion is just, any one may satisfy himself by the following experiment: fill a hollow glass globe with water, and suspend it in the sun, in such a manner that it may be raised or lowered at pleasure; at a certain height above the eye of the spectator, who looks at it with his back to the sun, the globe will appear to be red; let it then be slowly lowered, and it will appear to be orange, and afterwards, in succession, as it descends, it will appear yellow, green, blue, indigo, and violet. Hence the same drop of rain, which must be considered as a little globe, supplies all the seven colours to the eye. There are sometimes two rainbows seen at the same time, one within the other, and, what may seem remarkable, the order of the colours of the exterior bow is the reverse of that of the interior one. When two bows are seen, the exterior one is comparatively faint, and it is, therefore, sometimes called the false or secondary bow; while the greater distinctness of the interior one has obtained for it the appellation of the primary bow. To trace the progress of a ray of light through a drop of rain in each of these bows, will explain the cause of their differing in brightness. In the true or primary bow, the rays of light arrive at the spectator's eye after two refractions and one reflection.*

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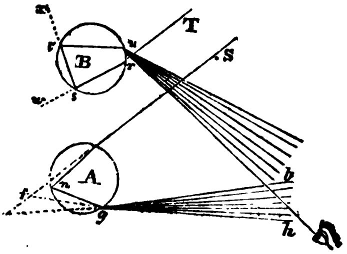
* The rainbow was one of those phenomena which astonished and perplexed the ancients; and, after many absurd and unsuccessful conjectures, their best philosophers, Pliny and Plutarch, relinquished the enquiry as one which was above the reach of human investigation. In the year 1611, Antonio de Dominis made a considerable advance, however, towards the theory of the rainbow, by suspending a glass globe in the sun's light, when he found that, while he stood with his back to the sun, the colours of the rainbow were reflected to his eye



Thus, let A, in the above diagram, be a drop of rain, and S a ray from the sun falling on the upper part of the drop. It will suffer a refraction, and instead of going forward in a right line, it will be bent to *n*; at *n*, part of it will emerge, but the remainder will be reflected to *g*; at *g* it will be again refracted on passing into the air towards the eye at *h*; being thus twice refracted and once reflected, the ray is separated into its primitive colours; the red part, which is least thrown out of its course, makes an angle, at its emergence, with the incident solar ray of forty degrees two minutes, as S*f h*; and the violet, being the most easily thrown out of its course, makes with the solar light an angle of forty degrees seventeen minutes. The different colours, therefore, at the distance of the spectator, are considerably separated, and affect the eye in succession with the seven colours; but the succession is so quick, and so many drops fall through the same circuit in the same time, that the mind loses the idea of succession, and the bow seems permanent as long as the shower continues in a proper direction for the eye.

in succession by the globe, as it was moved higher or lower. He was, however, unable to account for the production of the different colours, as the experiments with the prism had not yet been made, and it was reserved for Newton to perfect the discovery.

The exterior or secondary bow is formed by two reflections and two refractions. Let B represent one of the drops of rain forming this bow; a ray, T, from the sun, falling upon it at *r*, is refracted, and falls upon the back of the drop at *s*; from the transparency of the drop, a portion of it passes through towards *w*, but the remainder of it is reflected towards *t*; here again, for the same reason as before, part of it emerges from the drop, in the direction *x*, but the portion still left is reflected to *u*, where it is refracted towards the spectator, with the red rays uppermost. The great quantity of light lost at each reflection, is the cause of the indistinctness of this bow, and therefore we cannot be surprised that we rarely, if ever, see bows formed by a still greater number of reflections within the drops; for though they may exist, they are too faint to be seen. The secondary bow cannot be seen when the elevation of the sun is above fifty-four degrees seven minutes, and it is broader than the interior bow, because the rays are more dispersed before they reach the eye.

Very beautiful effects resulting from the decomposition of white light are visible on the surface of the feathers of birds, and are also exhibited on the surface of mother-of-pearl, and may readily be imitated on steel, and most transparent bodies. Dr. Brewster, while pursuing a series of experimental investigations on this subject, found, by the aid of the microscope, that they arose from grooves in the striated surface; that they were produced when the flat surface was unpolished, and that they could be communicated to wax, gum-arabic, tinfoil, the fusible metal, and even to lead, by hard pressure, or the blow of a hammer. He determined also, that the mottled colours upon all bodies with an imperfect polish, and the scratches or grooves upon polished metals, could be communicated to wax and other substances. The same structure which gives these communicable colours, he succeeded in producing artificially on the surface of calves-feet-jelly, that had been boiled a considerable time; and he discovered, with a powerful microscope, the same minute grooves which exist in mother-of-pearl, and they were so near one another, that some thousands of them must have been contained in a single inch. These grooves were completely visible to the unassisted eye, but they gave in a very distinct manner the colours of mother-of-pearl.

Mr. Barton, of the Mint, has succeeded in ornamenting steel and other articles, with the colours of striated surfaces, and of applying this principle to practical purposes.

In applying the principle of striated colours to ornament steel, the effect, or pattern, is produced upon the polished surface by the point of the diamond, so that either the whole or a part of the surface is covered with lines or grooves, whose distance may vary from the 1000th to the 10.000th of an inch. When these lines are most distant, the prismatic images of the candle, or any luminous body, seen by reflection from the polished surface, are nearest one another, and the common colourless image; and when the lines are least distant, the coloured images are farthest from one another, and the colours are most vivid.

In daylight, the colours produced by these minute grooves are scarcely distinguishable, unless at the boundary between a dark and a luminous object. In sharp lights, however, and particularly in that of the sun, the colours shine with extraordinary brilliancy, and the beautiful tints which accompany every luminous image, can only be equalled by their matchless exhibition on the reflections of the diamond.

The colours transmitted by plates of glass containing a film of air or water, are well worth an attentive examination. The plates of reflection or transmission of the several colours in a series are so near each other, that the colours dilute each other by mixture, whence the number of series in the open daylight seldom exceeds seven or eight: but if the system be viewed through a prism, by which means the rings of various colours are separated, according to their refrangibilities, they may be seen on that side towards which the refraction is made, so numerous, that it is impossible to count them. Or, if in a dark chamber, the sun's light be separated into its original rays by a prism, and a ray of one uncompounded colour be received upon two glasses, the number of circles will become very numerous. In this experiment it is also seen, that in any series, the circles formed by the less refrangible rays exceed in magnitude those which are formed by the more refrangible rays, and, consequently, that in any series, the more refrangible rays are reflected at less thicknesses than those which are less refrangible. If the light be incident obliquely, the rings of colours dilate and enlarge themselves; whence it follows, that the thickness required to reflect the colours of any series is different in different obliquities.

Water, applied to the edges of the glasses, is attracted between them, and filling all the intercedent space, becomes a thin plate similar to the air. In this case, the rings become much fainter, but vary not in their species, and are contracted in diameter nearly in the proportion of 7 to 8; consequently the intervals of the glasses, at like circles, caused by these two mediums, water and air, are as about 3 to 4; that is, nearly as the sines which measure the angles of incidence and refraction, made at a common surface between them. And hence it may be suspected, that if any other medium, more or less dense than water, be compressed between the two glasses, their intervals at the rings caused thereby, will be to the intervals at which similar rings are caused by the interjacent air, as the sine which measures the refraction made out of air into that medium is to the sine of the incidence on the common surface.

These are some of the phenomena of light incident on mediums which are environed by mediums of greater density, as air or water, compressed or included between plates of glass. The same appearances follow, though with some little variation, when the colorific medium is denser than that in which it is inclosed.

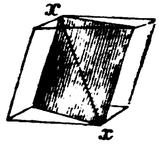
It is well known that bubbles blown in soap-water exhibit a great variety of colours; but as these colours are commonly too much agitated by the external air to admit of any certain observation, it is necessary that the bubble be covered with a clear glass, in which situation the following appearances ensue: the colours emerge from the vertex or top of the bubble, and as it grows thinner by the subsidence of the water, they dilate into circles or rings, parallel to the horizon, which slowly descend and vanish successively at the bottom. This emergence continues till the water at the vertex becomes too thin to reflect the light, at which time a circular spot of an intense blackness appears at the top, which slowly dilates, sometimes to three-quarters of an inch in breadth, before the bubble breaks.

The refraction of light, we have seen, is attributed to a power of attraction appertaining to all bodies, and exerted at a little distance from their surfaces; reflection, on the contrary, is produced by a power of repulsion, and also takes effect before the light actually strikes the reflecting surface. If these attractive and repulsive energies have any real existence, the rays of light, under certain circumstances, will be bent, in a manner that cannot be classed under either refraction or reflection. Accordingly, we find, that if a ray of light pass very near a body, without impinging upon it, it is bent inwards, or towards the body; this change in the direction of the ray is called inflection:—if the ray pass at a greater distance, it is bent outwards, or from the body:—this change in the direction of the ray is called deflection. When a beam of the sun's light passes through a hole in a window shutter, the image thrown upon a screen or an opposite wall, is larger than it would be if the rays, crossing at the aperture, proceeded in straight lines from the circumference of the sun's disk to the wall. It becomes, therefore, an object of enquiry, to determine the cause by which it has been expanded; and we find on close examination, that the side of the aperture has inflected, or caused it to diverge from the axis of the beam, the rays which have passed near it all around. *Inflection* was first discovered by Grimaldi, who made many curious experiments and observations relative to it; but the following experiments of Sir Isaac Newton will be better adapted than Grimaldi's to explain the nature of this property of light. At the distance of two or three feet from the window of a darkened room, in which there was a hole three-fourths of an inch broad, to admit the light, he placed a black sheet of pasteboard, having in the middle a hole about a quarter of an inch square, and behind the hole the blade of a sharp knife, to intercept a small part of the light which would otherwise have passed through the hole. The planes of the pasteboard and blade were parallel to each other, and when the pasteboard was removed to such a distance from the window, that all the light coming into the room must pass through this hole in the pasteboard, he received what came through the hole on a piece of paper, two or three feet beyond the knife, and perceived two streams of faint light shooting out both ways, from the beam of light into the shadow. As the brightness of the direct rays obscured the fainter light, by making a hole in his paper he let them pass through, and had thus an opportunity of attending closely to the two streams, which were nearly equal in length, breadth, and quantity of light. That part which was nearest to the sun's direct light, was pretty strong for the space of about a quarter of an inch, decreasing gradually till it became imperceptible; and at the edge of the knife it subtended an angle of about twelve, or at most of fourteen degrees. Another knife was then placed opposite to the former, and he observed, that when the distance of their edges was about the four-hundredth part of an inch, the stream divided in the middle, and left a shadow between the two parts, which was so dark that all the light passing between the knives seemed to be bent to each other; this shadow grew broader, till upon the contact of the knives the whole light disappeared. He observed, also, fringes of different-coloured light, three made on one side by the edge of one knife, and three on the other side by the edge of the other. Grimaldi, Dr. Hooke, and all the philosophers who made experiments on inflection before the time of Newton, ascribed the broad shadows, and even the fringes which he mentions, to the ordinary refraction of the air; but the investigation upon which he entered to discover their cause, afforded him satisfactory evidence to conclude that bodies have the power of acting upon light at a distance.

We must now briefly notice the experiments of Mr. Brougham on this interesting subject: they are detailed in the Transactions of the Royal Society for 1796. He commenced by admitting a beam from the sun into a darkened room, through a hole in a metal plate (fixed in the window shutter) of $\frac{1}{40}$th of an inch in diameter; and all other light being absorbed by black cloth hung before the window in the room, at the hole he placed a prism of glass, whose refracting angle was 45°, and which was covered all over with black paper, except a small part on each side, which was free from impurities, and through which the light was refracted, so as to form a distinct and homogeneous spectrum on a sheet of paper, at six feet from the window. In the rays, at two feet from the prism, he placed a black unpolished pin, one-tenth of an inch in diameter, parallel to the paper, in a vertical position, its shadow was formed in the spectrum on the paper, and had a considerable penumbra, especially in the brightest red. It varied very materially in its width; in the violet, it was broadest and most distinct; in the red, it was narrowest and most confused; and in the intermediate colours, it was of an intermediate degree of distinctness. It was not bounded by straight, but by curvilinear sides, which were concave outwardly. This figure of the shadow was not owing to any irregularity in the pin, for the same thing happened with all sorts of bodies that were used; and also, if the prism was caused to revolve on its axis, so that the colours might ascend and descend on these bodies, still, wherever the red fell, it made the least, and the violet the greatest shadow. In the next place, he fixed a screen, having in it a large hole, on which was a brass plate, pierced with a small hole of $\frac{1}{43}$ of an inch in diameter; then causing an assistant to move the prism slowly on its axis, he observed the round image made by the different rays passing through the hole to the paper; that made by the red was greatest; by the violet, least; and by the intermediate rays of an intermediate size. When he employed the sharp blade of a knife, so as to produce the fringes mentioned by Grimaldi and Newton, those fringes in the red were broadest, and most moved inwards to the shadow, and most dilated when the knife was moved over the hole; and the hole itself on the paper was more dilated during the motion, when illuminated by the red, than when illuminated by any of the other rays, and least of all when illuminated by the violet. From these, and a great variety of other experiments, well devised, and often repeated with the greatest care, he infers, that the rays of light are separable into their primitive colours, by inflection, deflection, and reflection, as well as by refraction; that these properties of the rays are inversely as their refrangibilities; that is, those which deviate the least by refraction, deviate the most by flection, and are reflected the farthest from the perpendicular; and that these different phenomena are all produced by the differences in the magnitude of the particles. He calculates that the size of the red particles are to those of the violet as 1275 to 1253. This he extends to all the other colours by similar calculations, their sizes lying between 1275 and 1253; which are the extreme red, and extreme violet; the red, therefore, according to this hypothesis, is from 1275 to 1272½; the orange from 1272½ to 1270; the yellow from 1270 to 1267; the green from 1267 to 1264; the blue from 1264 to 1260; the indigo from 1260 to 1258; and the violet from 1258 to 1253.

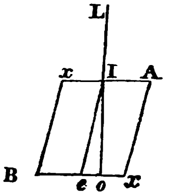
The *polarization* of light is an important part of the science of optics. It has been usual to commence this subject by considering the well-known phenomenon of double refraction, which is exhibited by all crystals, the primitive form of which is neither the cube nor regular hexahedron. Of all known bodies, the Iceland spar, or rhomboidal carbonate of lime, shows the fact with the greatest certainty; and as it is a mineral easily procured, and of sufficient size and transparency, it has been generally made use of for this purpose. The crystals of this substance have the form of a rhomboid, having six acute solid angles, and two obtuse. These last, x and x, fig. 1, are formed by the junction of three equal plane angles, which are equally inclined to each other. The line x, x, joining these two angles, is, therefore, similarly situated with respect to the three planes forming each angle, and is called the *axis of the crystal.* A plane, perpendicular to the natural surface of the crystal, and coinciding with this line, is called its *principal section,* which term is also applied to any plane parallel to this section.

Fig. 1.



It is well known, that an object seen through the crystal in its natural form (that form to which it is easily brought by cleavage,) will give two images, one of which will appear in its situation according to the common law of refraction, while the other will be observed thrown towards the lower obtuse angle, but always in the plane of the principal section. (The most convenient method to examine these facts, is to pierce a small hole through any opaque plate, which may be applied to the lower surface of the crystal, and directed to a sheet of white paper.) Let x A, x B, fig. 2, be the principal section of the crystal, and L a pencil of light falling on its surface: one part of the light will proceed in the ordinary direction, (we will suppose perpendicularly,) and is, therefore, called the ordinary ray, while the other portion of the light deviates considerably from this direction, and is called the extraordinary ray.

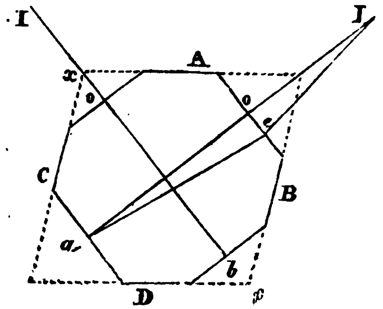
Fig. 2.



In fig. 2. I *o* will represent the ordinary, and I *e* the extraordinary ray.

Let the crystal be cut by two planes A B, and C D, fig. 3. parallel to the axis, and two other planes A C, and D B, perpendicular to the axis, to allow an object to be seen through it in the direction A C, or A B, it will be found that the two images will be farther separated, viewed in the direction A C, which is perpendicular to the axis, while in the direction of the axis there will be only one image. The inference from these experiments is, that there exists some peculiar force acting on the light passing through the crystal, producing a separation of the rays, and that this force emanates from the axis itself. As this produces a deviation of the second image towards, or from, the axis of the crystal, it is considered as positive or negative, or according to Biot, attractive or repulsive.

Fig. 3.



The two rays into which a pencil of light is divided in passing through a crystal of Iceland spar, are always of the same intensity, and always in the plane of the principal section. But the two emerging rays are not only diminished in intensity by the division of the light between them, but have undergone a most important modification.

If the rays be made to pass through another crystal, placed similarly to the first, there will be no subdivision of the light; the two images will be merely separated to a greater distance, from the increased thickness through which the light passes. If now the two crystals are so placed, that the principal sections are at right angles to each other, there will still be only two images, but the ray ordinarily refracted in the first, will become extraordinary in the second, and the extraordinary, ordinary. But at all intermediate positions of the two crystals there will be a subdivision of each ray, and consequently four images: these four images will be of equal intensity when the principal sections of the two crystals are at an angle of 45° to each other; at all other angles, one or other of the images diminish in intensity, as the principal sections approach to a perpendicular, or to a parallelism; not by the coalescence of the two images, but by the gradual diminution of the intensity of one, and by the augmentation of that of the other. In the three diagrams, fig. 4, 5, and 6, we have supposed the rhomboids reduced to the form of cubes: in each the axis is denoted by x x, the direction of the rays by the lines passing through the figure, and the extraordinary and ordinary rays by the letters *e* and *o*. It is thus seen that each emerging ray is only subject to a farther division, in particular positions of the second crystal; whereas natural light is always divided into two portions of equal intensity. Each ray suffers a physical change; it is not acted on by the force of the second crystal, as natural light would be, but requires that the force be applied in a particular direction relatively to the modification it has received from the first crystal. This has been called polarization. We know nothing of the poles, nor of the molecules to which these poles are said to belong; polarization must be considered merely as a conventional term to express a phenomenon; and to avoid the repetition of the conditions producing it, it is usual to consider the poles of the ordinary ray as coinciding with the principal section of the crystal, and those of the extraordinary ray with a plane perpendicular to it.

Fig. 4.

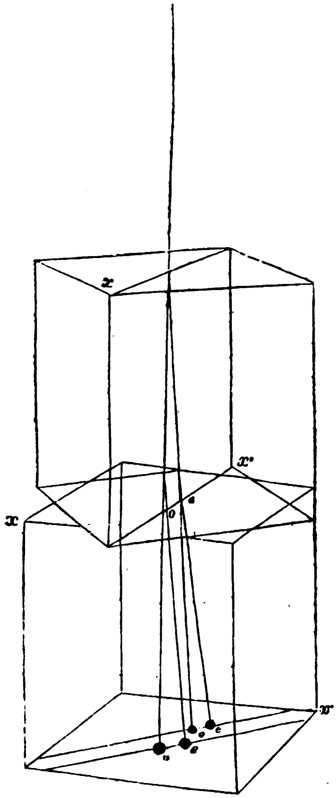


Fig. 5.

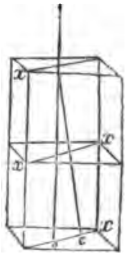
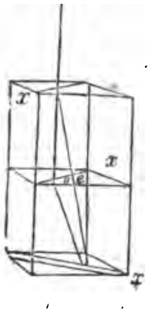


Fig. 6.



In these experiments an effect is produced on the two rays, by their passing through a crystal, which so modifies them, that it requires the action of a second crystal to be exerted in two directions, at right angles to each other, to produce a similar effect. As direct light is always divided into two rays of equal intensity by a double refracting crystal, it may be used as a test to discover and ascertain the direction of polarization.

When light is reflected from the surface of transparent bodies, it is found to be polarized in the plane of reflection, more or less completely, according to the angle formed with the surface. This angle varies for different substances, and to Dr. Brewster we are indebted for a law connecting the angle with the index of refraction of the given body, viz. "that the tangent of the angle of polarization measured from the perpendicular, is equal to the index of refraction," when complete polarization, or the greatest the body is capable of, is produced.

The index of refraction is a number having the same proportion to 1, that the sine of the angle of incidence has to the sine of the angle of refraction. It is, therefore, constant for all angles of incidence in the same body. It is generally calculated for light passing from a vacuum into the given body.

From this law are deduced three consequences:—

1. That the complement of the angle of polarization is equal to the angle of refraction.

2. That the reflected ray is perpendicular to the refracted ray.

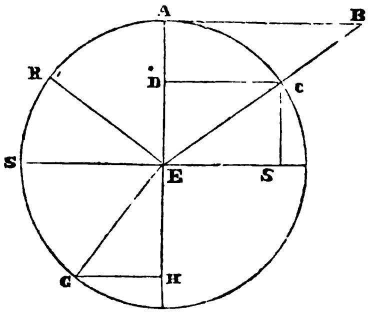
3. That the angles of polarization and refraction are together equal to a right angle.

Let C E, fig. 7. be the incident ray at the angle of complete polarization, R E the reflected ray, and E G the refracted ray.

The sine D C : sine G H : : index : 1

But index=tangent A B; and radius A E=1

Fig. 7.



As A B : A E : : D C : G H

A B : D E : : D C : D E ∴ G H=D E=C S, and the angle C E S=angle G E H.

2dly, H E S is a right angle, from which is taken G E H; but as G E H=C E S=R E S. R E S+G E S=a right angle.

This law gives an easy method to determine the angle of polarization of any body of which the index of refraction is known. Look in a table of tangents for the given index as a tangent, and the corresponding angle will be the angle of polarization. If such a table be not at hand, let S S be the surface, and A E drawn perpendicularly: from a scale make A B=index, A E being 1. Join B E, and the angle A E B will be the required angle.

The index is generally given, for light passing from a vacuum; if it be required to determine the index under other circumstances, divide the index of the given body by the index of the medium from which it passes, and the quotient will be the index required. In bodies, the opacity of which prevents the direct measurement of the angle of refraction, the angle of polarization gives the index of refraction, if this law be rigorous, which it appears to be, for all bodies which have been yet examined; though M. Fresnel seems to think that it is rather an approximation.

We may here remark that some authors give the angle of polarization measured from the surface: and sometimes the index of refraction is calculated on the passage from air.

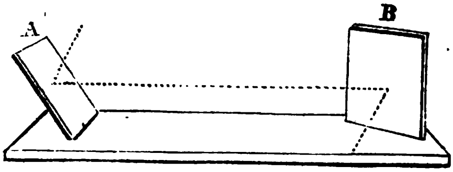
Malus and Biot state, that the peculiar influence of crystals is not exerted on light reflected from their surfaces; and that the angle of polarization is the same whether the plane of incidence be parallel, perpendicular, or oblique, to the principal section of the crystal. But Dr. Brewster found a difference of more than 2°. He found the angle of polarization to be 57° 14'. when the incidence was in the plane of the principal section, and 59° 32' when in a plane perpendicular to it. The surface was that produced by a careful cleavage of the crystal.

One of the first laws of optics is, that "light falling on a plane mirror is reflected at an angle equal to the angle of incidence;" but if this mirror be transparent, the light so reflected is found to have received a polarity in the plane of reflection, more or less complete as the angle of incidence approaches the angle of polarization for the substance employed. In fact there is some trace of polarization discernible in light reflected from every body, at every angle of incidence except the perpendicular; but this in so feeble a degree, that we may consider it, at present, insensible, except from transparent bodies.

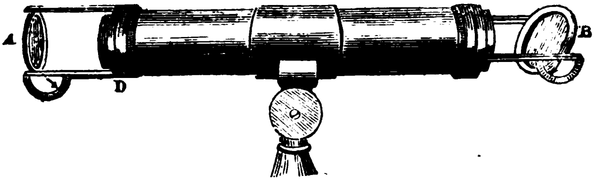
We have already explained that there are, for some bodies, certain angles, at which complete polarization takes place; in some others, though very transparent, yet of high refractive power, complete polarization does not take place at any angle, as in the diamond; in others, as black marble, ebony, black varnishes, &c. in which the refractive density is less, complete polarization takes place, though they be opaque. This angle for water is 52° 45' from the perpendicular, and for glass about 55°.

In our explanation we may have recourse to an instrument, which, though not indispensable, will be found useful in many experiments where accuracy is required. But for the satisfaction of any one as to the general facts, two pieces of unsilvered mirror glass are all that will be essential, as in the annexed figure. The reflected ray is seen to

Fig. 8.



descend upon the plate A, which would have been polarized if the angles had been 35°, and consequently not reflected. But partial polarization is produced by the plate B.



The above instrument hardly requires description. It consists of a tube having a frame at each end, holding reflectors, A and B, which are capable of being adjusted to any angle with the axis of the tube, and of being turned round the tube, so that the planes of reflection may be at any angle to each other. Suppose the two mirrors (of unsilvered glass) inclined on their axis to the polarizing angle 55° to the incident ray, remove the mirror B, and make a ray of natural light, passing through the axis of the tube, fall on the mirror A, it will be found that the light will be reflected equally in whatever direction the mirror is turned by the ring D, whether upwards or downwards, to the right or to the left. Let now the mirror B be replaced, and the apparatus so placed that the light reflected from it fall on the other mirror A; if the plane of reflection of the two mirrors coincide, that is, if the plane of each reflection is towards the same direction, to an eye placed opposite A, there will be a reflection of a considerable part of the light incident on it. After being satisfied that there is in this position a partial reflection of the light, turn the ring D a quarter round either to the right or left, and with it the mirror A, (the inclination of which to the axis remains the same,) and on looking on the mirror there will be now found a total obscuration, that is, no light will be reflected, the whole passing through the glass. To be satisfied that this does not take place from any accidental derangement of the instrument, it is only necessary to turn the mirror slowly from one position to the other, and a gradual diminution of the intensity will be observed, passing from its maximum in the first position, to complete obscuration in the last, or when the plane of the first reflection is at right angles to what would have been the plane of the second reflection had the light been direct.

A farther proof that this is no deception, is afforded by substituting a metallic reflector in the place of the mirror B; in which case, no such alteration takes place.

To return to the experiments. Continue to turn the mirror A gradually in the same direction, so that the reflection is again parallel to the first, but in an opposite direction, and the light will be again at a maximum; and if the mirror be still turned in the same direction until it has made three-fourths of a revolution, the light reflected will again be reduced to nothing.

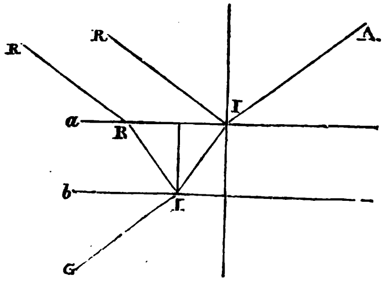
In this experiment we see that light, having been reflected from a surface at a certain angle, is entirely transmitted by another mirror, if the plane of incidence on the second mirror is perpendicular to the plane of incidence on the first, while natural light would have been equally reflected in every position.

It must be observed, that if the angle of reflection of either mirror be greater or less than the angle of polarization, there will not be a total obscuration. The angle made by the two planes of reflection, is often called the azimuth. To succeed perfectly in this experiment, the back of each mirror should be blackened, to prevent the admission of extraneous light. It will now be not difficult to show, that the direction of polarity in the reflected light is, to the plane of reflection, similar to the polarity of the ordinary ray in Iceland spar, to its principal section, or an identity of the modification produced in the reflected ray, and the modification produced by the action of the crystal on the ray ordinarily refracted; for, if the ray reflected from water or glass at the polarizing angle be received on a crystal of Iceland spar, the principal section of which coincides with the plane of reflection, the ray entering the crystal will proceed through it in the same direction that the ordinary ray, emerging from another crystal, would have proceeded. But if the principal section of the crystal be placed perpendicular to the plane of reflection, the ray will be refracted extraordinarily; but in both positions there will be no bifurcation of the ray. If the principal section of the crystal be any otherwise situated, as to the plane of reflection, there will be two rays, but of equal intensity, when the angle contained between these two planes be 45°. If, again, the ordinary ray emerging from a crystal be made to fall at the proper angle, on the surface of water, or any other reflecting surface capable of polarizing light completely, it will be reflected when the principal section and plane of reflection coincide, but entirely transmitted when the planes are perpendicular to each other. But if the extraordinary ray fall on the surface, the reflection will take place when the planes are at right angles, and a total transmission will result when the planes coincide.

We are therefore justified in assuming that the physical change the light has suffered, is the same in the two cases. That whether an ordinary ray be examined by subsequent reflection, or the reflected ray by a doubly refracting crystal, the inference is, that the polarity of each is in the same direction: the one in the plane of the principal section, and the other in the plane of reflection.

Light is not only reflected from the first surface of transparent bodies, but another portion is reflected from the second surface. We will suppose these two surfaces parallel,

Fig. 9.



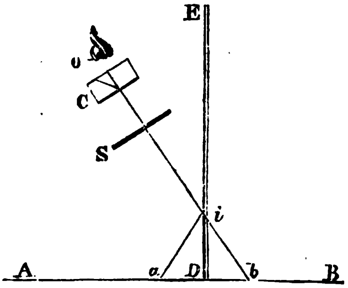
and it will not be difficult to see, that if the light be competely polarized by reflection from the first surface *a*, the portion reflected from the second surface *b* will also be completely polarized, and in the same plane.

Let A I be the incident ray, and I R the reflected polar ray; I I, the refracted ray, partially reflected and afterwards refracted to R′ and I′ G, the remaining refracted light will be perpendicular to I′ R′, the reflected ray, a condition we have seen before producing complete polarization.

From various experiments it has been proved, that the quantity of light reflected even from the two surfaces of a transparent body, is small in proportion to the incident light; and it is now convenient to inquire the condition of the refracted portion, under circumstances in which polarization of the reflected light is produced. If the ray I G be examined by a rhomboid, it will be found divided into two rays, but not of equal intensity; for the ordinary or extraordinary ray will be found the most intense, as the section of the crystal is parallel or perpendicular to the plane of refraction. This condition of light is called partial polarization, and is the same as the state of reflected light when the incidence is not such as to produce complete polarization.

M. Arago gives the following experiments:

Fig. 10.

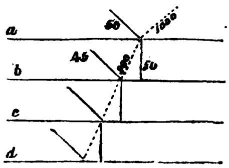


Let us suppose a plate of glass, E D, placed perpendicularly on a sheet of fine white paper A B, the eye placed at O will see at the same time the reflected ray *a*, *i*, *o*, and the refracted ray *b*, *i*, *o*. Interpose an opaque plate perforated with a small hole S; let the eye at O be furnished with a doubly refracting crystal C: if by a black screen placed between *b* and *i*, we stop the ray *b i*, which would have been transmitted by the glass plate, the hole in the plate S is illuminated by the reflected light alone; and if the principal section of the crystal coincide with the plane of reflection, we see two images of the pole, of which the ordinary is the most brilliant. If the screen be now so placed as to intercept the reflected ray *a*, *i*, *o*, there will be still two images, but now the extraordinary will be the most brilliant.

Now, if the screen be entirely removed, allowing both reflected and refracted light to reach the crystal, the intensity of the two images is found by actual experiment to be exactly equal. It is hence to be inferred, that the plane which contains the poles of light, polarized by transmission, is perpendicular to the plane which contains poles of light polarized by reflection; and that the quantity of polarized light, contained in the ray transmitted by a transparent plate, is exactly equal to the quantity of polarized light contained in the ray reflected from its surface, whatever the angle of incidence may be. M. Arago observes, that a body which, at its angle of complete polarization, reflects half the incident light from its surface, will also completely polarize the transmitted ray; and that when there is no transmission of light there is no polarization. This seems proved experimentally, as no trace of partial polarization is discoverable in the light reflected from the interior of a glass prism, when the reflection is total.

As transparent substances reflect but a small portion of the incident rays, the quantity of polarized light in the transmitted rays is small in proportion to the light which has not undergone that modification. Dr. Brewster considers the transmitted ray as consisting of one portion completely polarized in a plane at right angles to the plane of incidence, and another portion of light "which has suffered a physical change more or less approaching to complete polarization." Light having passed through a pile of plates, is at last polarized in a plane perpendicular to the plane of polarization of the reflected light. "This effect requires the agency of twenty-four plates at an incidence of 61°; consequently," says Dr. Brewster, "twelve plates will not polarize the whole pencil at that angle. Let us now suppose that the quantity not polarized amounts to twenty out of a hundred, then if these twenty were absolutely unpolarized, and in the same state as direct light, they would require to pass through twenty-four plates in order to be completely polarized. But experiments prove that they require to pass only through twelve other plates to be completely polarized; it therefore follows, that the twenty rays have been half polarized by the first twelve plates, and the polarization completed by the other twelve."

This reasoning may be good, but as Malus, Biot, and Arago, consider this partially polarized light to consist of light completely polarized, and light in the state of direct or natural light, and as this view of the question admits of a ready explanation, we shall adopt it.

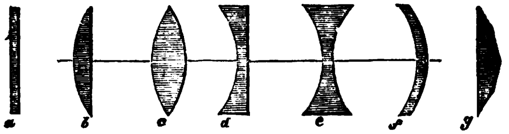


Let *a*, *b*, *c*, *d*, be supposed to represent the successive plates through which the incident ray 1000 is to pass, and at a given angle, 50 out of the 100 be completely polarized by reflection, and a similar quantity of rays by refraction; the light emerging from the first lamina will consist of 900 in the state of direct light, and 50 of light polarized in a plane perpendicular to the plane of incidence. We have already seen that light polarized in one plane, will not be reflected in a plane perpendicular to its plane of polarization, and consequently the portion 50 of transmitted light will escape reflection from the lamina *b*, and therefore the light reflected from *b*, which we have supposed $\frac{1}{10}$th of the incident light, must be taken from the 900 of direct light. In this manner we may suppose the quantity of direct light constantly diminished, and the polarized light increased by each succeeding transmission. According to this view, complete polarization could never be produced, but the quantity of direct light, after a few transmissions, would be absolutely imperceptible.

It cannot be necessary to explain the result of submitting the ray emerging from a succession of plates to another pile of plates, to a doubly refractive crystal, or to a reflection from a polarizing surface. In all these cases its polarization relatively to the plane of incidence on the first surface is precisely similar to the extraordinary ray transmitted by a crystal, relatively to its principal section.

We will, however, mention one consequence of the foregoing laws; that polarized light falling on the first surface of a pile of plates, will be partially reflected when the plane of incidence coincides with the plane of polarization; and a farther portion being also reflected at each successive plate, an eye placed at the back of the plates will receive no sensible quantity of light. If, on the contrary, the plane of polarization be perpendicular to the plane of incidence, the whole light will be transmitted. It therefore follows, that an apparatus may be constructed of the most transparent plates of glass, in two piles or bundles, forming a system perfectly transparent in one position of the piles, yet perfectly opaque in another. This effect is only to be produced by a great number of plates of glass, if the incidence be near the perpendicular; yet some substances possess this property of polarizing transmitted light, whatever the incidence. A thin plate of tourmaline cut parallel to the axis of the crystal, completely polarizes the light at any incidence in a plane perpendicular to the axis; and a second plate will transmit or stop all the rays, as the axis of the two plates are parallel or perpendicular to each other.

A *lens* is a transparent body of a different density from the surrounding medium, commonly of glass, and used by opticians to collect or disperse the rays of light. They are in general either convex, that is, thicker in the middle than at the edges, which collect, and by the force of refraction, converge the rays, and consequently magnify; or concave, that is, thinner in the middle than at the edges, which, by the refraction, disperse the rays of light, and diminish the objects that are seen through them.



A plano-convex lens is represented at *b*, while *c* is a double convex: *d*, a plano-concave; *e*, a double concave; *f*, the meniscus formed lens; and *g*, a lens ground with a series of flat surfaces, usually employed to multiply or encrease the apparent number of objects. The plane plate of glass at *a*, is merely employed to show the difference between a lens and a mere transparent medium which does not produce any peculiar optical effects.

The principal focus, or focus of parallel rays, in convex lenses, is readily ascertained upon mathematical principles. It may, however, be found with sufficient accuracy for common purposes, by holding a sheet of paper behind the glass, when exposed to the rays of the sun, and observing when the luminous spot is smallest, and when the paper begins to burn. Or when the focal length does not exceed three feet, it may be found by holding the glass at such a distance from the wall opposite a window sash, as that the sash may appear distinct upon the wall. It will be observed, that in a double convex lens, the rays of light are twice refracted: first, on entering the convex surface of the dense medium, the glass; and secondly, on going out of the same dense medium, and entering the rare medium, or the air, which, from the form of the glass, we know, must present a concave surface. Now, rays are equally converged by entering a convex surface of a dense medium, and a concave surface of a rarer medium. The focus of a double convex lens, then, is at only half the distance of the focus of one which has only one convex surface, that is, a plano-convex. The focus of a double convex lens, therefore, is the length of the radius, or semi-diameter of that circle, which is formed by the convexity of either of its surfaces.*

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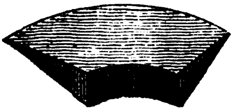
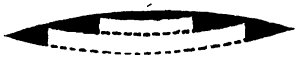
* To acquire a practical acquaintance with the laws of refraction and the properties of lenses, the student should make experiments with lenses of different foci, diameters, and colours. The room should be darkened, and the sun's rays admitted through an aperture cut in the shutter. The lenses should be fitted into cells connected with a sliding board, or adapted to convenient frames. By these means the lenses may be combined in any required way. It would be proper,

Owing to the great difficulty that arises in the casting and grinding the ordinary lens, when of large dimensions, it has been proposed by Dr. Brewster to construct them of a series of zones, or rings, as is shown in the section beneath, accompanied by one of the segments.





By this combination of segments, a lens of large size may be formed, and will obviously possess the same properties as if it consisted of solid glass. The advantages of this construction may be very shortly enumerated. The difficulty of procuring a mass of flint glass, proper for a solid lens, is in this construction completely removed. If impurities exist in the glass of any of the spherical segments, or if an accident happens to any of them, it can be easily replaced at a very trifling expense. Hence, the spherical segments may be made of glass much more pure and free from flaws and veins, than the corresponding portions of a solid lens.

From the spherical aberration of a convex lens, the focus of the outer portion is nearer the lens than the focus of the central parts, and, therefore, the solar light is not concentrated in the same point of the axis.* This evil may, in a

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also, to have lenses ground to the figure of a meniscus, or watch-glass, and fitted up so that two or more of them might be connected in one frame, so as to include fluids between them, and thus exemplify the refractive powers of fluid lenses. The dust usually in motion will, in the darkened room, give the various and natural figures of the converging and diverging rays with tolerable accuracy.

[*] The axis of a lens is a line supposed to be drawn through the

great measure, be removed in the present construction, by placing the different zones in such a manner that their foci may coincide.

A lens of this construction may be formed by degrees, according to the convenience and means of the artist. One zone, or even one segment, may be added after another, and, at every step, the instrument may be used as if it were complete.

If it should be thought advisable to grind the segments separately, or two by two, a much smaller tool will be necessary, than if they formed one continuous lens. But, if it should be reckoned more accurate to grind each zone by itself, then the various segments may be easily held together by a firm cement. Each zone may have a different focal length, and may, therefore, be placed at different distances from the focal point, if it is thought proper.

From what we have seen of the nature of refraction and reflection, it will be evident that a burning lens must be convex, a burning mirror, concave; because both produce their effect by concentrating into a very small compass the rays of light and heat incident upon a large surface. As the rays which pass through a convex lens, or are reflected from a concave mirror, are united at its focus, their effect is so much the greater, as the surface of the lens or mirror exceeds that of the focus. Thus, if a lens four inches broad collect the sun's rays into a focus at the distance of one foot, the image will not be more than one-tenth of an inch broad. The surface of this little circle is 1600 times less than the surface of the lens, and, conse-

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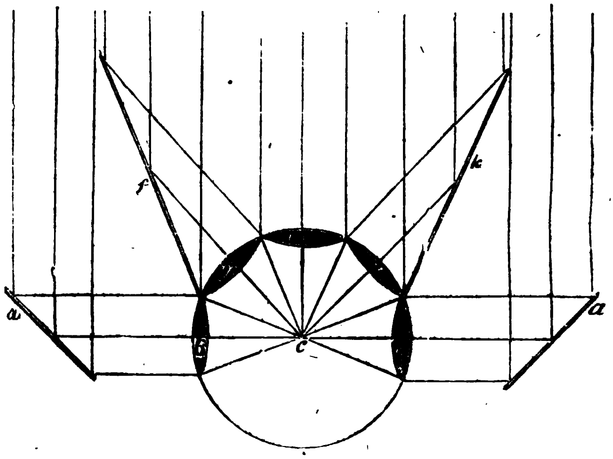
centre of its spherical surface, or surfaces. When one side of the lens is plane, the axis of course falls perpendicularly upon that side. The axis of a lens continued, would pass exactly through the centre of that sphere, of which the lens is the segment.

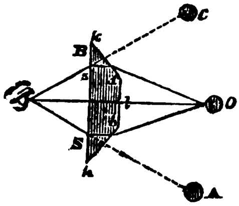
quently, the density of the sun's rays within it is proportionately increased. It is not, therefore, surprising, that large lenses and mirrors burn with irresistible intensity. The most remarkable burning lens which has ever been constructed, was made by Mr. Parker, at an expense of upwards of £700. It was undertaken with a view to fuse and vitrify such substances as resist the fire of an ordinary furnace; and more especially of applying heat in vacuo, and under other circumstances in which it cannot be applied by any other means. His lens was of flint glass, three feet in diameter, and when fixed in its frame, exposed a surface of two feet eight inches and a half in diameter, without any other material imperfection besides a disfigurement of one of the edges, occasioned by a piece of scoria, which had found its way into its substance. Its weight was two hundred and twelve pounds; the focal length being six feet eight inches, and the diameter of the focus one inch. To concentrate the rays still further, a second lens was used, and reduced the diameter of the focus to half an inch.

The principal phenomena elicited by Mr. Parker's lens may be thus described. Every kind of wood took fire in an instant, whether hard or green, or even soaked in water. Thin iron plates grew hot in an instant, and then melted. Tiles, slates, and all kinds of earth were instantly vitrified. Sulphur, pitch, and all resinous bodies melted under water. Fir-wood, exposed to the focus under water, did not seem changed, but when broken, the inside was burnt to a coal. Any metal whatever, inclosed in charcoal, melted in a moment, the fire sparkling like that of a forge. The substances most difficult to be operated upon, were those of a white colour. When copper was melted, and thrown quickly into cold water, it produced so violent a shock as to break the strongest earthen vessels, and the copper was entirely dissipated. Though the heat of the focus was so intense as to melt gold in a few seconds, yet there was so little heat at a short distance from the focus, that the finger might be placed about an inch from it without injury. Mr. Parker had the curiosity to try what the sensation was at the focus, and having put his finger there for that purpose, he described the sensation, not as resembling that produced by a fire or lighted candle, but like that of a sharp cut with a lancet.

Dr. Brewster has materially simplified the construction of the burning lens, and by combining reflection with refraction, he has suggested an arrangement unlimited in its power of action. Dr. B's *burning sphere* may be best understood by reference to the section beneath.



The lenses, of which sections are given, are so combined with the reflectors, as to form an entire circle with a common focus at c. The whole spherical surface, of which only a section is here represented, may be composed of lenses; each of which, with the exception of the central lens, is furnished with a plane mirror, as at *a a k f.* When this sphere is employed, it must be so placed, that the sun's rays fall at right angles upon the central lens, and they will be concentrated at *c*. The next lens is furnished with a large portion of the sun's rays by the reflector, and so on through the whole series of lenses; more than half the sphere being furnished with an arrangement of this description, while the reflector behind throws back any rays which may have passed the object to be ignited.



The *multiplying-glass* is made by grinding down the round side of a convex-glass B S, into several flat surfaces, as *k d*, *d b*, and *b k*. An object O will not appear magnified when seen through this glass by the eye; but it will appear multiplied into as many different objects as the glass contains plane surfaces. For, since rays will flow from the object O to all parts of the glass, and each plane surface will refract these rays to the eye; the same object will appear to the eye in the direction of the rays, which enter it through each surface. Thus, a ray O *l*, falling perpendicularly on the middle surface, will go through the glass to the eye, without suffering any refraction; and will therefore show the object in its true place at O: while a ray O *d*, flowing from the same object, and falling obliquely on the plane surface *d k*, will be refracted in the direction *d s*, by passing through the glass; and upon leaving it, will go on to the eye in the direction of *s*; which will cause the same object O to appear also at C, in the direction of the ray C *s*, producing the right line *s* C. And the ray A S, flowing from the object O, and falling obliquely on the plane surface *b k*, will be refracted to the eye, and as such cause the same object to appear at A, in the direction of A S. If the glass be turned round the central line, as an axis, the object O will keep its place, because the surface is not changed; but all the other objects will seem to go round O, because the oblique planes on which the rays fall, will go round by the turning of the glass.

From this brief view of the nature of refraction, as applied to lenses, it may be advisable to examine the most wonderful of all natural lenses, the *human eye.* For precisely upon the same principle as the ordinary double convex lens magnifies and inverts the objects viewed through it, upon the same principle does the natural lens paint upon the retina the various objects that fall within the field of vision.

The eye, though the most wonderful, and at the first view the most complicated part of animal anatomy, is in reality nothing more than a camera-obscura; the various humours forming one powerful lens of an exceeding short focal distance on one side, while on the other, it is allowed to embrace a very considerable space, and this is called the field of vision.

In order that we may properly understand the nature of vision, it will be necessary to furnish a brief anatomical description of the eye; which is composed of several coats or cases, one within the other, and filled with transparent humours of different degrees of density. The outer coat of the eye is called the sclerotica. It is exceedingly strong, and the muscles that move the eye are attached to it. What is called the white of the eye, is a part of this coat. The cornea bulges out a little from the eyeball; it is circular, and exceedingly transparent. The next coat to the sclerotica is called the choroides, which serves as a lining to it. It is of a dark colour in the human eye, but white in cats and owls, and green in most animals that live on grass and vegetables. Its texture is soft and pulpy, and too weak to be susceptible of muscular motion, except at its extremities towards the front of the eye. Like the sclerotica, it is distinguished into two parts; the fore part being called the iris, while the hinder part retains the name of the choroïdes. The iris commences immediately under the commencement of the cornea. It there attaches itself more strongly to the sclerotica by a cellular substance, forming a kind of white, narrow, circular rim, called the ciliary circle. The iris is that remarkable circle, which gives the eye its character as to colour; it is composed of two sets of muscular fibres; the one tending, like radii, towards the centre of the circle, and the other forming a number of concentric circles round the same centre. The central part of the iris is perforated, and the aperture, which is called the pupil, is always round, but varied in diameter by the action of the two sets of muscular fibres composing the iris. When a very luminous object is viewed, the circular fibres contract, the radial are relaxed, and thus the size of the pupil is diminished; on the other hand, when the objects are dark and obscure, the radial fibres of the iris contract, the circular are relaxed, and the pupil is enlarged, so that it admits a greater quantity of light. By candle-light, the contraction and dilation of the pupil may be very distinctly observed, with the assistance of a looking-glass. If, with our eyes directed to the mirror, we bring the candle close to our face, we shall find the pupil become very small; if the candle be removed, and completely shaded for about a minute, and then brought to its former place, it will be found that the pupil has greatly dilated, and that it again contracts as the light draws nearer: if the light shine much more strongly on one eye than the other, the pupil of the shaded eye will not contract so much as the other. The whole of the choroide membrane is opaque, by which means no light can enter the eye but what passes through the pupil: but to render the chamber of the eye still darker, the posterior surface of this membrane is covered with a dark-coloured mucus, called the pigmentum. Under the iris, there is a prolongation of the choroides, which forms a circular band of radial fibres, turning inwards towards the centre of the eye, and filled up between with a black mucus, giving it the appearance of a membrane. This circular band is called the ligamentum ciliare, or ciliary ligament. The third and *last* coat of the eye is called the retina. This is a fine and delicate membrane, being an expansion of the optic nerve, which proceeds from the brain. It is spread like a net of exquisite delicacy, all over the concave surface of the choroides, and terminates at the ciliary ligament. It receives the images of objects, which are depicted upon it by the rays of light that enter at the pupil. It is of itself transparent, and of an ash-coloured white, but appears black on account of the dark-coloured pigmentum behind it. The optic nerve which passes through a small hole in the bony cavity containing the eye, and conveys to the sensorium the impressions made on the retina, is not in the centre of the eye, but a little on one side, inclining towards the nose.*

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* A controversy was agitated in the latter part of the seventeenth century, concerning the seat of vision: some contending that this function was performed by the retina, and others attributing it to the choroides. The most powerful argument used against the retina is, that the pencils ought to be converged on an uniform surface, to form a distinct image; whereas the retina is irregular, perfectly transparent, and presents no such surface. On the other hand, it is more consonant to physiology to suppose this sense, as well as every other, lodged in the nerves: and the retina, being an expansion of the optic nerve, seems intended by Providence as the organ of this sense.

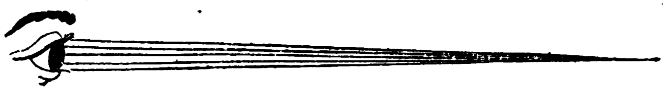
The tunica choroides is described by some authors as consisting of two laminæ. This description, however, applies much more accurately to the eyes of some animals, particularly to those of sheep, than to those of man. Those who suppose the choroides to consist of two laminæ, describe the external one as terminating at the ciliary ligament, and the internal one as extending further to form the iris. The iris is described as consisting of two laminæ, and it is very certain that two sets of fibres may be observed. These are supposed to be muscular, and from the mobility of the iris there seems no reason to doubt of their being really so. Some of the fibres are orbicular, and lie round the pupil; others are straight, and extend from the circumference of the iris to its centre. We have seen that the iris has motions of such a nature, that the pupil is contracted on the approach of a strong light, and is dilated in proportion as the light is less vivid. By this admirable yet simple contrivance, the eye adapts itself to the different proportions of light to which it is exposed. If the iris was always as much contracted as it is when exposed to the light of noon-day, a weaker light, such as that of the moon, could not be admitted in sufficient quantity to answer any useful purpose. On the contrary, if the pupil was immovably dilated, we might take advantage of the scattered rays of light, but should be distressed and blinded by the bright effulgence of the mid-day sun. When a strong light succeeds to darkness, we are under the necessity of closing the eyelids, or of turning away the head, till the pupil has been accommodated to the change by the contractile powers of the iris.

The three transparent substances inclosed by the coats of the eye are called the aqueous, crystalline, and vitreous humours. The first of these, or *aqueous* humour, resembles water, whence its name. It gives a protuberant figure to the cornea, filling the two cavities between the cornea and ciliary ligament, which cavities communicate by the pupil. The refractive power of the aqueous humour is similar to that of water. The second, or *crystalline* humour, is like the former, transparent, in which it exceeds that of the purest crystal; it has the consistence of a hard jelly, growing somewhat softer from the middle towards the edges. Its form is that of a double convex lens, but more convex on the interior than the exterior surface. Resembling a lens in its form, it also resembles one in its use: it converges the rays which pass through it from every visible object to its focus on the retina. It is inclosed in a fine transparent cover, or membrane, which is attached to the ligamentum ciliare, and by that means it is suspended. The radial fibres of the ligamentum ciliare have the power of contracting and dilating occasionally, by which means they alter the shape or convexity of this natural lens, and shift it a little backward or forward in the eye, so as to adapt its focal distance from the retina to the different distances of objects. Without this, or some equivalent arrangement, we should only see those objects distinctly that were at one distance from the eye. At the back of the crystalline lies the third, or vitreous humour. The *vitreous* humour was so called from a supposed resemblance to melted glass; it is a clear and gelatinous fluid, very much resembling the white of an egg. It fills about three-fourths of the globe of the eye, and extends from the posterior part of the eye as far as the ciliary ligament. It is contained in a fine transparent capsule, or membrane, and when carefully removed from the globe of the eye, preserves its consistence for some time, being supported by its capsule, but afterwards runs off, and the capsule diminishes in size. The thin capsule which surrounds the vitreous humour, sends off a number of membranous processes into the vitreous substance, where they form cells, which communicate with each other, and afford a high degree of firmness and tenacity to the whole mass.

Dr. Brewster has very accurately ascertained the amount of refraction in the various coats and humours of the human eye, as well as the relative measures of those bodies; and as the results differ from those of Dr. Wollaston and others, who had previously examined the subject, they may be considered of considerable importance in the anatomy as well as the optical properties of that organ. Taking the refractive power of water at 1.3358, the following table will convey the result of Dr. B's. experiments.

Refractive power of the aqueous humour	1.3366
Vitreous humour	1.3394
Outer coat of crystalline	1.3767
Middle coat of ditto	1.3786
Central part of ditto	1.3990
Whole crystalline	1.3839

	Inch.
Diameter of the crystalline	0.378
Cornea	0.400
Thickness of the crystalline	0.172
Cornea	0.042



Above, is shown a pencil of rays, radiating from a luminous point; and these, when they arrive at the surface of the cornea, form cones, the points of which are at the object, and the bases on the cornea. Those which impinge on the opaque sclerotica are reflected, and have no concern in the production of vision: while those which, by falling very obliquely, form a very considerable angle with the cornea, are also reflected without penetrating into the aqueous humour. The rays, which fall within an angle of about forty-eight degrees, pass through this membrane, undergoing a certain refraction, by which they are brought nearer to the line of the axis of the cornea; and, if produced, would converge into a focal point beyond the bottom of the eye. From the cornea, the rays pass into the aqueous humour. They are there divided by the dispersive powers of this fluid, so that, if continued in the same medium, they would not only converge beyond the back of the eye, but on account of the aberration caused by their different refrangibility, would produce a confused and coloured image.

The rays collected by the cornea pass through the pupil. Those which come in an unfavourable direction are either reflected by the iris, or absorbed by the pigmentum on its posterior surface. The pupil admits only those rays which are nearest to the axis of vision. They then meet with the crystalline, which, by its refractive power, collects them, and brings them into foci, after passing through the less refractive medium of the vitreous humour on the concave surface of the retina.

They do not impart a correct perception of the body which reflects them, unless they fall on the retina precisely in the order in which they are detached from that body. To produce this effect, it is necessary that all the rays which proceed from any one point, should be collected in one point of the retina; and that all the points of union thus formed, should be disposed in the same manner as in the body, of which they form an image.

The cone of rays which proceeds from any luminous point to the cornea, forms another cone, the apex of which falls on the retina. These two cones have their axes almost in a straight line. That which is perpendicular to the middle of the crystalline proceeds directly to the bottom of the eye; that which comes from above falls inferiorly; that on the left proceeds to the right, and so on with respect to the others; thus an inverted image is formed on the retina.

There are five natural methods by which we judge of the distance of objects from the eye. 1st. by the angle which is made by the optic axes; for want of this direction, it has been observed, that persons who are blind of one eye, frequently make a slight mistake as to the situation of objects. Secondly, by the apparent magnitude of the objects. By depending upon this method, we are frequently deceived in our estimates of distance by any extraordinary large objects; as in approaching a large city, or edifice, we fancy them nearer than they really are. This furnishes us with a reason why animals and other small objects seen contiguous to large mountains appear exceedingly small; for we imagine the mountain to be nearer to us than it actually is. When we look down also from a high building, the objects beneath us appear much smaller than they would at the same distance on the level ground; the reason is, plainly, because we have no distinct idea of distance in that direction, and therefore judge by the impressions upon the retina, whereas custom has corrected our judgment in the other case. The third method of determining the distance of objects is by the force and vividness of the colours; and the fourth is analogous to it; namely, by the different appearance of the minute parts. When these appear distinct, we judge the object to be near; and the contrary, when they appear faint and confused. Fifthly, we are assisted in judging of the distance of any particular object, by the other objects which are interposed. On this account distances upon uneven ground do not appear so great as upon plain; for the valleys, rivers, and other objects that lie low, are many of them lost to the sight. This, too, is the reason why the banks of a river appear contiguous, when the river lies low and is not seen.

Though every object that is before our eyes has its image in both organs, yet objects are not seen double; because, having previously ascertained, by help of the touch, that such an object was single, at the same time that each optic axis was directed towards it, and its image was painted in the corresponding parts of each retina, we have connected the idea of unity with the sentiment of those impressions, and have accustomed ourselves to identify two sensations, which, so to speak, are in unison with one another. But if the two optic axes no longer concur towards the same point, as when we slightly press one eye sideways with the hand, the object appears double, and it is evident that the two images do not then fall on the corresponding parts of the retina.

It has often been a subject of inquiry, why we see objects in their true position, though the image on the retina is inverted, but no satisfactory solution of the difficulty has ever been given. And we should be as little likely to receive an answer, if we were to ask, why we do not perceive every object bent, because the image of it is depicted upon a concave surface. It is certain, that unless distinct images are painted on the retina, objects cannot be clearly perceived. If from too little light, remoteness, or any other cause, a picture is indistinctly painted on the retina, an obscure or indistinct idea of the object is conveyed to the mind. The picture on the retina is, therefore, so far the cause of vision, that our ideas of visible objects vary as it varies, and when it is not formed, nothing is seen. Yet we may fairly conclude, that the mind does not look upon the image on the retina; for in cases of the gutta serena, a disorder which affects only the optic nerve, the pictures on the retina are as perfectly formed as in the best eyes, although the patient is afflicted with incurable blindness. It is the optic nerve, therefore, which conveys the impressions made on the retina to the brain; but how they are communicated to the mind, is screened from the view of man. It has been supposed that we acquire by experience the habit of seeing objects erect; but there are many striking facts to prove the contrary: persons who have been blind from infancy, and who have been suddenly restored to sight by a surgical operation, have not been led into the smallest mistake. In fact, no reason can be given why the mind should not perceive as accurately the position of bodies, when the rays reflected from the upper part of those bodies fall upon the lower parts of the eye, as if the contrary took place.

The impressions of light on the retina appear to be always in a certain degree permanent, and the more so as the light is stronger; but it is uncertain whether the retina possesses this property merely as a phophorescent body, or in consequence of its peculiar organization. The duration of the impression is usually limited to less than half a second: hence, a luminous object revolving in a circle, makes a lucid ring; and a shooting star leaves a train of light behind it, which is not always real. If the object is painfully bright, it generally produces a permanent spot, which continues to pass through various changes of colour for some time, and then gradually vanishes. Dr. Roget, in an ingenious paper published in the Transactions of the

Royal Society, has farther illustrated this subject by reference to the revolution of a wheel made to revolve behind a series of perpendicular bars.

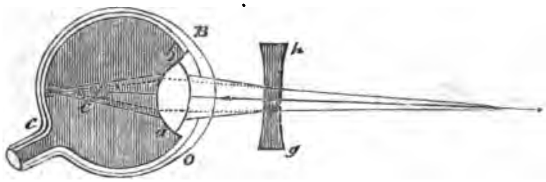
It may now be advisable to examine another, and no less important part of the anatomy of this organ, or the arrangement made for its protection from any inconvenience that may arise from the attacks of insects, or the particles of dust which are continually floating in the air. This is effected by the *eyelids*, which, like two substantial curtains, protect and cover the eyes when we are asleep; and, while waking, they diffuse, by their motion, and by peculiar secreting organs, a fluid over the eye, which cleans and polishes it.

The *eyebrows* also defend the eye from the rays of light which might otherwise prove too strong for the optic nerve; and that the *eyelid* may shut with greater exactness, each edge is stiffened by a cartilaginous arch, from which proceed the eyelashes, thus serving to warn the eye of dangers, while it protects it from the straggling mote.

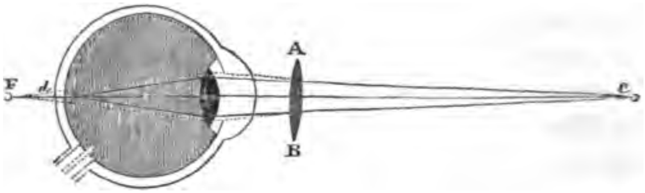
The more we investigate the works of nature, the greater reason have we to admire the wisdom of its Author; and that wonderful adaptation of our organs, in the minutest particulars, to the general laws which pervade the universe. The mechanism of the eye affords a striking illustration of this remark. We have hitherto supposed the eye to be a lens possessing the power only of enlarging and contracting its dimensions; and from the previous description given of the rays of light, it may be considered as incapable of obviating the confusion which must arise from their different degrees of refrangibility. But here the use of that wonderful structure of parts, and the different fluids in the eye, is clearly seen. The eye is, in fact, a compound lens; each fluid has its proper refrangible power. The shape of the lenses is altered at will, according to the distance of the object; and the three substances having the proper powers of refrangibility, the effects of an achromatic glass are without difficulty produced by the eye.

The causes which produce *defective vision* must now be examined.

There are two most important morbid affections of the eye, and these produce indistinct vision by directly opposite means. The first is caused by the cornea, and crystalline, or either of them, being too convex, or the distance between the retina and crystalline being too great. It is evident, that from either of these causes, or both of them combined, the distinct picture of an object, at an ordinary distance, will fall short of the retina, and, therefore, the picture on that membrane must be confused, which will also render vision confused and indistinct; so that, in order to see things distinctly, people whose eyes are so formed, are obliged to bring the object very near their eyes; by which means the rays fall upon the cornea in a more diverging state, and as such, distinct vision is effected: from the circumstance of such persons being obliged to hold objects near their eyes, in order to see them distinctly, they are called short-sighted.



A case of this kind is shown by the dotted lines in the accompanying diagram, in which the rays, by diverging from the focal point to the retina, will form a very confused image; and as such, the observer will have an indistinct view of the object. This inconvenience is remedied by placing a concave glass *g h*, before the pupil *o* B, which glass, by causing the rays to diverge between it and the eye, lengthens the focal distance, so that if the glass be properly chosen, the rays will unite at the retina, and form a distinct image of the object upon it; *a b* serves to mark the boundary of the crystalline lens, and *c* shows the optic nerve.



Another cause of defective vision may now be noticed. It is evident from the above figure, that if either of the humours be too flat, the focal point of the rays *e*, will not be on the retina, but beyond the eye, as at F. Consequently, those rays which flow from the object *c*, and pass through the humours of the eye, are not converged enough to unite at *d*, but pass on to F, and as such, the observer can have but a very indistinct view of the object. This is remedied by placing a convex glass A B, of a proper focus, before the eye; which makes the rays converge sooner, and imprints the image duly on the retina at *b*.*

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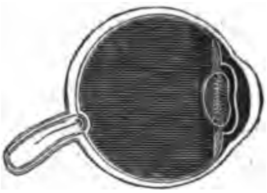
* If a short-sighted person look at an object through a small hole made in a card, he will be able to see even remote objects with tolerable distinctness, for this lessens the circle of dissipation on the retina, and thus lessens the confusion in the picture. For the same purpose, we commonly observe short-sighted people, when they wish to see distant objects more distinctly, almost shut their eyelids: " and it

In the preceding description of long and short vision, we have contented ourselves with furnishing such a view of the eye as was best calculated to explain the direction taken by the rays of light in approaching the retina; another view may, however, now be subjoined,[*] furnishing an exact representation of the interior of that important organ.



The ciliary process is here represented, faithfully copied from the anatomy of the organ, and the projecting form of the cornea immediately above the pupil, with its adaptation to the purposes of vision, may now be readily understood.

is from this," says Dr. Poterfield, "that short-sighted persons were anciently called myopes."

The sight of myopes, we have seen, is remedied by a concave lens of proper concavity, and they do not require different glasses for different distances. If they have a lens which will enable them to see distinctly at the distance most commonly used by other persons, for example, at the distance at which persons, whose eyes are good, generally read, they will, by the help of the same glass, be able to see distinctly, at all the distances at which good-sighted people can see distinctly; for the cause of short-sightedness is not a want of power to vary the conformation of the eye, but is owing to the whole quantity of refraction being too great for the distance of the retina from the cornea.

The other defect, it has been shown, is of an opposite nature, and persons labouring under it are called long-sighted, or presbytae: Whence, in order to read, such persons are obliged to remove the book to a great distance, which lessens the divergency of the rays falling on the eye, and makes them converge to a focus sooner, so as to paint a distinct image on the retina.

Some have conceived that the retina is not equally sensible in all its parts, and that a certain portion only, near the axis of the eye, is capable of conveying distinct impressions of minute objects. Comparetti says, that distinct vision is effected only in the optic axis, which is moved most rapidly over every point of the object; and that what is seen apparently out of the axis, is caused by the direction of the first impression in the axis. We believe, however, that the limits of distinct vision are far more extensive. Dr. Young, speaking of his own eye, says, that the visual axis being fixed in any direction, he can see at the same time a luminous object placed at considerable distances from it; the angle, however, differs. Upwards, it extends to fifty degrees, inwards to sixty, downwards to seventy, and outwards to ninety degrees. These internal limits of the field of view nearly correspond with the external limits formed by the different parts of the face, when the eye is directed forwards and somewhat downwards, which is its most natural position; and both are well calculated for enabling us to perceive the most readily such objects as are the most likely to concern us. The extent of the retina is every way greater than the limits of the field of view. The whole extent of perfect vision is little more than ten degrees; or, more strictly speaking, the imperfection begins within a degree or two of the visual axis, and at the distance of five or six degrees becomes nearly stationary, until, at a still greater distance, vision is wholly extinguished. The imperfection may be owing partly to the unavoidable aberration of oblique rays, but principally to the insensibility of the retina; for, if the image of the sun itself be received on a part of the retina remote from the axis, the impression will not be sufficiently strong to form a permanent spectrum, although an object of very moderate brightness will produce this effect, when distinctly viewed. The motion of the eye has a range of about fifty-five degrees in every direction, so that the field of perfect vision, in succession, is by this motion extended to one hundred and ten degrees.*

Dr. Monro has published some excellent remarks on the variety that appears in the eyes of different animals. He observes, that all quadrupeds have, at the internal canthus of the eye, a strong and firm membrane, with a cartilaginous edge, which may be made to cover some part of their eye; and this is greater or less in different animals, as their eyes are more or less exposed to danger in seeking after their food. This *membrana nictitans*, as it is called, is, however, not very large in all these animals. Cows and horses have it so large as to cover one-half of the eye, like a curtain, and at the same time it is transparent enough to allow abundance of the rays of light to pass through it. Fishes have a cuticle constantly over their eyes, as they are ever in danger in that inconstant element, the water.

All quadrupeds have a seventh muscle belonging to the eye, called *suspensorius*. It surrounds almost the whole optic nerve, and is fixed into the sclerotic coat as the others are. Its use is to sustain the weight of the globe of the eye, and to prevent the optic nerve from being too much stretched, without obliging the four straight muscles to be in a continual contraction, which would be inconvenient: at the same time, this muscle may be brought to assist any of the other four, by causing one particular portion of it to act at a time.

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* Mr. Adams in his "Essay on Vision," has given some useful rules for the preservation of the sight:—

1st. Never sit for any length of time in any gloom, or exposed to a blaze of light. From this rule may be deduced the impropriety of going hastily from one extreme to the other, whether of darkness or of light; and it may be inferred, that a southern aspect is improper for those whose sight is weak. 2. We should avoid reading any very small print. 3. Do not read in the dusk, nor, if the eyes are disordered, by candle-light. 4. The eye should not be permitted to dwell on glaring objects, more particularly on the first waking in the morning. 5. The long-sighted should accustom themselves to read with rather less light, and somewhat nearer to the eye than usual; while those who are short-sighted, should accustom themselves to read with the book off as far as possible.

The next thing to be remarked is the figure of the pupil, which is different in different animals, but always exactly accommodated to the creature's way of life, as well as to the different species of objects that are viewed. In man, it is circular; an ox has it oval, with the longest diameter placed transversely, to take in a large view of its food; in the cat, it is oval, but the longest diameter placed perpendicularly; they can either exclude a bright light altogether, or admit only as much as is necessary. The pupil of different animals varies in wideness, according as the internal organs of vision are more or less acute: thus cats, and owls, who seek their prey in the night, or in dark places, (and, consequently, must have their eyes so formed, as that a few rays of light may make a lively impression on the retina,) have their pupils in the day-time contracted into a very narrow space, as a great number of rays would oppress this delicate organ; while in the night, or where the light is faint, they open the pupil, and very fully admit the rays. In the same way, when the retina is inflamed, a great number of rays of light would occasion a painful sensation; therefore, the pupil is contracted; on the contrary, in dying people, it is generally dilated, as the eyes on such occasions are very difficultly affected, and in some measure insensible. The posterior part of the choroid coat, which is called the *tapetum*, is of different colours in different animals;

for oxen, feeding mostly on grass, have this membrane of a green colour, that it may reflect upon the retina all the rays of light which come from the objects of that colour, while other rays are absorbed: thus the animal sees its food better than it does other objects. Cats and owls have their tapetum of a whiteish colour; and for the same reasons have their pupil very dilateable, and their organs of vision acute: and we shall find, that all animals see more or less distinctly in the dark, according as their tapetum approaches nearer to a white or black colour. Thus dogs, who have it of a greyish colour, distinguish objects better in the night than man, whose tapetum is dark brown.

The *Microscope* is a most important optical instrument, and its construction will be best understood by a reference to its most simple form, which will be found nearly to resemble the eye.

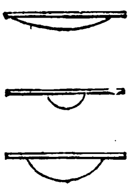
This instrument owes its power of magnifying objects to a judicious arrangement of glasses; and, in common language, the microscope is said to magnify the objects which are seen through it; this, however, is true, only with regard to their apparent, and not their real magnitude. The apparent magnitude of an object is measured by the angle under which it is seen by the eye. Hence, an object at the distance of half a mile, will appear twice as large as it would if it were at a mile's distance: because the angle which it would make on the eye would be twice as large in the one case as the other. Upon the same principle, if at the distance of six or seven inches we can but just discern an object, and then by interposing a lens, or other body, we can view that object at a nearer distance, the object will appear as much larger through the lens than it did to the naked eye, as its distance from the lens is less than its distance was from the eye. That this is not because the object is magnified by the lens is evident from the circumstance, that the same thing will happen if, instead of a lens, a piece of brown paper with a small hole, made with a pin or needle, be interposed between the object and the eye. If the edge be brought within an inch or two of a book, it will be impossible to distinguish the letters; but if, at the same distance, it be examined through a hole in the way already described, the letters will not only be visible, but apparently very much magnified. This would not be the case, if the letter was seen through the same hole at the distance of six or seven inches from it.

A variety of ingenious methods have been suggested for the construction of *microscopic spherules* possessing great magnifying power. The one best known, is to take up with the point of a wetted wire small fragments of crown glass, and placing them in the flame of a spirit-lamp, till, by producing fluidity, their particles may be enabled to take a spherical form. Another method consists in drawing out a thin strip of glass into threads, and afterwards holding the extremities of the threads in the flame of a lamp till they take the same form as the melted fragments. The spherules thus formed, may be afterwards detached from the filament which supported them, and being placed between two thin plates of metal, pierced with a small aperture, they form a useful miscroscopic instrument. Mr. Siveright has, however, effected a considerable improvement in these instruments, and his mode of constructing them is thus described:—Take a piece of platinum-leaf, about the thickness of tinfoil, and make two or three circular holes in it, from 1-20th to 1-10th of an inch in diameter, and at the distance of about half an inch from each other. In the holes put pieces of glass, which will adhere to them without falling through, and which are thick enough to fill the apertures. When the glass is melted at the flame of a candle with the blow-pipe, it forms a lens, which adheres strongly to the metal, so that the lens is formed and set at the same time. The pieces of glass used for this purpose should have no mark of a diamond or file upon them, as the mark always remains, however strongly they are heated with the blowpipe, and they should not exceed one-tenth of an inch in diameter; an eye or loop, made by bending the extremity of a platinum wire, may be used instead of the platinum-leaf. Mr. Siveright has also formed a plano-convex lens by means of fusion; to effect which, he took a plate of topaz, with a perfectly flat and polished natural surface, and having laid a fragment of glass upon it, he exposed the whole to an intense heat. The upper surface of the glass assumed a spherical surface, in virtue of the mutual attraction of its parts, while that beneath became perfectly flat and smooth from its contact with the stone.

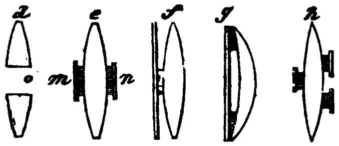
Dr. Brewster has very materially improved the construction of *fluid microscopes*. An apparatus of this kind was originally suggested by Mr. Stephen Gray. They consisted merely of a drop of water, which was taken up on the point of a pin, and placed in a small hole one-thirtieth of an inch in diameter, in the middle of a spherical cavity, about one-eighth of an inch broad, and a little deeper than half the thickness of the plate. On the opposite side of the plate was another spherical cavity, half as broad as the former, and so deep as to reduce the circumference of the small hole to a sharp edge. When the water is placed in these cavities, it will form a double convex lens with unequal convexities, which may be employed like any other single microscope in the examination of minute objects.

As water, however, has a considerable dispersive power, and a low power of refraction, fluid microscopes of a more perfect kind may be formed, by using sulphuric acid, castor oil, oil of ambergrease, or alcohol. The sulphuric acid has a very low dispersive power, and a greater refractive power than water, and will, therefore, make a more perfect lens than any other fluid body. Castor oil may be employed with almost equal advantage; and oil of ambergrease and alcohol would answer the same purpose, from their optical properties, though their volatility may render them less easily managed.

The best method of constructing fluid microscopes, is to take Canada balsam, balsam of Copaiba, or pure turpentine varnish, and let a drop of any of them fall upon a thin piece of parallel glass. The drop will form a plano-convex lens, and its focal length may be regulated by the quantity of fluid which is used. These fluid lenses are represented beneath, supported by plates of glass. If the lens is uppermost, the gravity of the fluid will make it more flat, and diminish its focal length. This, however, may be avoided, and the contrary effect produced, by inverting the piece of glass. If these lenses are preserved from dust, they will be as durable as those which are made of glass; and when thick Canada balsam is used, the lenses will soon be indurated into a hard gummy substance, and resist any change of figure from the gravitation of their parts.



The same ingenious philosopher has proposed a valuable mode of adjusting microscopes, so that the observer can obtain distinct vision, while viewing objects situated at different distances. To effect this, when the more remote of the two points which are to be seen at the same time, is at a greater distance than seven or eight inches, the shortest limit of distinct vision, the adjusting microscope may be formed by drilling a small hole through the lens as at *d*, or by cementing upon the centre of each of its surfaces two small circular pieces of glass, with a drop of Canada balsam, shown at *e*. The central part of the lens will thus be reduced to a plane surface, as is seen in the diagram.



When the rays from the more distant point pass through the perforation *o*, or through the planes *m n*, and fall upon the central part of the pupil, they will form a distinct image of it upon the retina; while the rays from the nearer point, passing through the lens, will be incident upon the outer portion of the pupil, and form an equally distinct image of it upon the retina. If the distance of both the points is less than seven or eight inches, a plane of glass *f*, should be cemented to the lens *d*, by any viscid fluid, which has such a refractive power, that the encreased focal length of the central part of the lens may be to its real focal length, as the distance of the remoter point is to the distance of the nearer point. The remoter point will then be seen distinctly through the central portion of the lens, while the nearer point will be seen with equal distinctness through the outer portion. The same effect will be produced by the memiscus-formed lens *g*, and with its plane, where the cement forms a ring at the circumference of the lens.*

In order to see three points at the same instant with perfect distinctness, we must adopt the construction shown at *h*, where a very small circular plane of glass its cemented by Canada balsam to the anterior surface of the lens, and a small circular ring of glass, cemented on the opposite side to the portion of the lens immediately surrounding the first circular plane. The lens will thus be divided into three zones, having three different focal lengths, which may be varied in any required proportion, by altering the radii of the two surfaces, or changing the refractive power of the cement. In order to avoid any loss of light arising from the circumferences of the glass planes not being transparent, each of them may be extended to the very circumference of the lens.

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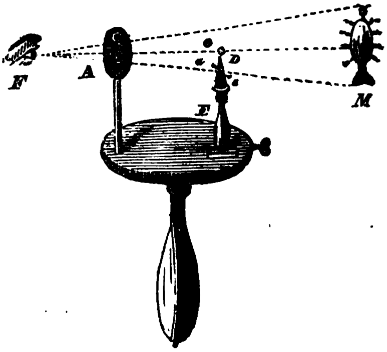
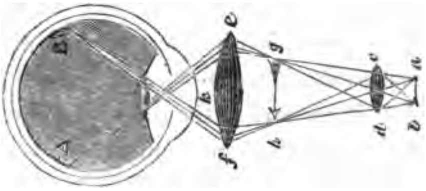
* Vide Brewster on New Philosophical Instruments.

The form of a very convenient microscope is shown beneath; consisting of a circular stand of mahogany, perforated with a small aperture, in which is placed a wire, supporting a small lens C, whose focal distance is C D. At that distance is a pair of plyers D E, which may be adjusted by means of the sliding screw, as in the figure, and opened by means of the two little studs *a e*; with these the observer may take up any small object O, and view it with the eye placed in the other focus of the lens at F; and according to the focal length of the lens, the object O



will appear more or less magnified, as represented at M. If the focal length be half, or one-fourth of an inch, the length, surface, and bulk of the object will be magnified, as before described. This small instrument may be put into a case, and carried about in the pocket without inconvenience. Lenses whose focal lengths are from three to five-tenths of an inch, are best calculated for common use.

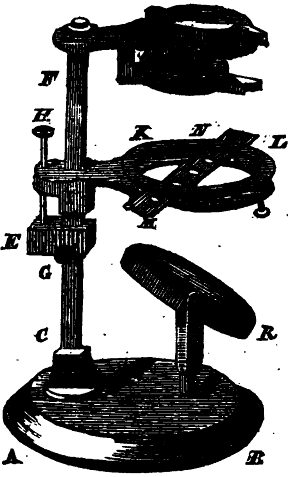
The double or *compound microscope* differs from the preceding in this respect, that it consists of at least two lenses, by one of which an image is formed within the tube of the microscope, and this image is viewed through the eye-glass instead of the object itself, as in the single microscope. In this respect, the principle is analagous to that of the telescope, which we shall presently examine; only that, as the latter is intended to view distant objects, the object-lens is of a long focus, and consequently of a moderate magnifying power, and the eye-glass of a short focus, which magnifies the image made by the object-lens. But the microscope being intended only for minute objects, the object-lens is of a short focus, while the eye-glass, in this case, is not of so high a magnifying power.



This compound microscope consists of an object-glass *c d*, and an eye-glass *e f*. The small object *a b*, is placed at a little greater distance from the glass *c d*, than its principal focus, so that the pencils of rays flowing from the different points of the object, and passing through the glass, may be made to converge and unite in as many points between *g* and *h*, where the image of the object will be formed; which image is viewed by the eye through the eye-glass *e f*; for the eye-glass being so placed, that the image *g h*, may be in its focus, and the eye about the same distance on the other side, the rays of each pencil will be parallel after going out of the eye-glass, as at *e* and *f*, till they come to the eye at *k*, where they will begin to converge by the refractive powers of the humours; and after having crossed each other in the pupil, and passed through the crystalline and vitreous humours, they will be collected into points on the retina, and form the large inverted image A B.

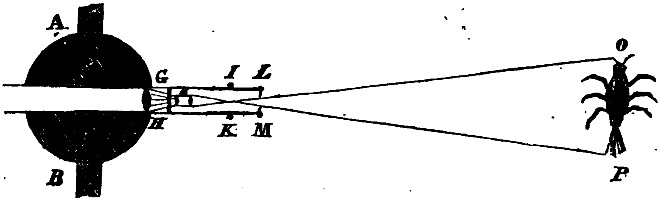
The magnifying power of this microscope is as follows: if we suppose the image *g h* to be six times the distance of the object *a b* from the object-glass *c d*, then will the image be six times the length of the object; but since the image could not be seen distinctly by the bare eye at a less distance than six inches, if it be viewed by an eye-glass *e f*, of one inch focus, it will be brought six times nearer the eye, and consequently viewed under an angle six times as large as before, so that it will be again magnified six times, that is, six times by the object-glass, and six times by the eye-glass, which, multiplied into one another, makes thirty-six times; and so much is the object magnified in diameter more than what it appears to the unassisted eye.

The accompanying diagram represents a very valuable, as well as portable microscope. A B is the basis or foot, C the stem, and E F two square sockets of brass, moveable upon the square part of the stem, being connected by a common screw. This motion is checked by the constant pressure of a spring. G is a screw by which the part E is fixed to the stem. H is an adjusting-screw, by which the part F is gradually moved up and down; so that the stage K L, on which the objects are placed, has M N the slider, with its objects, duly adjusted to the focus of the magnifiers. O is a circular piece of brass, on which are fixed three lenses, turning on centres fixed in O, and which may be used either separately, or combined together; R is the speculum that reflects the light through the microscope.



Dr. Wollaston has proposed an improvement of microscopes, which he thinks highly advantageous. The great desideratum, he observes, in employing high magnifiers, is sufficiency of light; and it is accordingly expedient to make the aperture of the little lens as large as is consistent with distinct vision. But if the object to be viewed is of such magnitude as to appear under an angle of several degrees on each side of the centre, the requisite distinctness cannot be given to the whole surface by a common lens, in consequence of the confusion occasioned by the oblique incidence of the lateral rays, excepting by means of a very small aperture, and proportionable diminution of light. In order to remedy this inconvenience, he used two plano-convex lenses ground to the same radius, and applied their plane surfaces on opposite sides of the same aperture in a thin piece of metal. Thus he virtually obtained a double convex lens, with this advantage, that the passage of oblique rays was at right angles with the surfaces, as well as the central pencil. With a lens so constructed, the perforation that appeared to give the most perfect distinctness was about one-fifth part of the focal length in diameter; and when such an aperture is well centred, the visible field is at least as much as twenty degrees in diameter. It is true, that a portion of light is lost by doubling the number of surfaces, but this is more than compensated by the greater aperture, which, under these circumstances, is compatible with distinct vision.

We may best illustrate the interior of a microscope with a moveable tube and scioptric ball, by a figure.



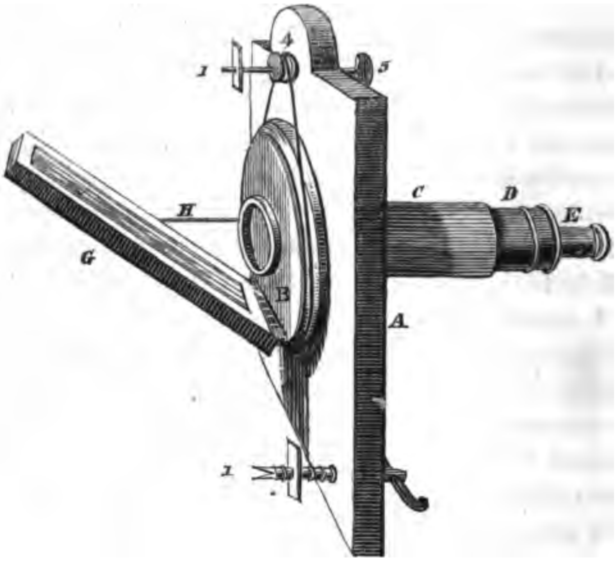
Let A B be a section of the window-shutter of a dark room, containing a scioptric ball E F, in the forepart of which is screwed the tube G I K H, at one end of which is a lens G H, which, by converging the sun-beams into a narrow compass, strongly enlightens the small object *a*, placed on a slip of glass or talc, in the tube G H, where a slit is made on each side for that purpose. Within this tube there is another slider, L M, which contains a small magnifying lens.

By moving the exterior tube I G H K, the glass G H may be brought to receive the rays of the sun directly, and will therefore most intensely illuminate the object *a*. The other tube L M, being slid backwards and forwards, will adjust the distance of the small lens, so that the image of the object *a* shall be made very distinct on the opposite side of the room, at O P; and the magnitude of the image will be to that of the object, as the distance from the lens M L is to the distance of the object from it.

The *camera-obscura microscope* is usually composed of a tube, a reflecting mirror, and a convex lens, in addition to the ordinary microscopic apparatus. The sun's rays being directed by the looking-glass through the tube upon the object, the image or picture is thrown distinctly and beautifully upon a screen of white paper, or a white linen sheet, placed at some distance to receive it, and considerably magnified.

The apparatus for this purpose, as represented in the accompanying engraving, is as follows: A, a square wooden frame, through which two long screws pass, and by means of two nuts 1 1, fasten it firmly to a window-shutter, in which a hole is made for its reception, the two nuts being let into the shutter.

A circular hole is made in the middle of this frame, to receive a piece of wood of a circular figure B. The edge projects a little beyond the frame, and contains a shallow groove, furnished with a band, which, by twisting round, and then crossing over a brass pulley 4, affords an easy motion for turning round the circular piece of wood B, with its connecting parts, to follow the course of the sun.



C is a brass tube, screwed into the middle of the circular piece of wood, forming a case for the uncovered brass tube D, which may be drawn backwards or forwards. E, a smaller tube, of about one inch in length, screwed to the end of the larger tube D.

In the large tube is a convex lens, whose focus is about twelve inches, designed to collect the sun's rays, and throw them more strongly upon the object. G, a looking-glass of an oblong figure, set in a wooden frame, fastened by hinges to the circular piece of wood B, round which it revolves.

H, a jointed wire passing through the wooden frame, to enable the observer, by putting it backwards or forwards, to elevate or depress the glass, according to the sun's altitude.

When the microscope is employed, the room must be rendered as dark as possible; for, on the darkness of the room, and the brightness of the sun-rays, depend the sharpness and perfection of the image. Then putting the looking-glass G, through the hole in the window-shutter, the observer must fasten the square frame A, to the said shutter, by its two screws and nuts 1 1.

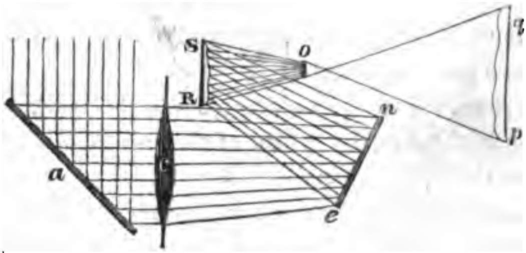
This done, adjust the looking-glass to the elevation and situation of the sun, by means of the jointed wire H, together with the pulley and band.

As soon as this appears, screw the tube C into the brass collar provided for it in the middle of the woodwork, taking care not to alter the looking-glass; then screwing the magnifier to be employed, to the end of the microscope, take away the lens at the other end, and place a slider, containing the object to be examined, between the thin brass plates, as in the common microscope.

Things being thus prepared, screw the body of the microscope to the short brass tube E, and pull out the tube D, less or more, as the object is capable of enduring the sun's heat. Dead objects may be brought within about an inch of the focus of the convex lens; but the distance must be altered for living insects, or they will speedily be deprived of life.

The short tube E, which the microscope is screwed to, enables the observer, by moving it backwards or forwards in the tube D, to bring the objects to their true focal distance, which will be known by the sharpness and clearness of their appearance; they may also be turned round by the same means, without the effect being injured.

The solar microscope we have just been examining, is calculated only to exhibit transparent objects, or at least such as permit a part of the incident light to pass through them; to view opaque objects, another mirror must be used, in order that they may be seen by the light that they reflect.



In the above figure, the mirror *a*, and the lens *c*, are the same as in the common solar microscope; but the converging rays from *c* are met by a mirror *e n*, placed diagonally, and which reflects the rays upon the opaque object S R; from the object they are reflected to the magnifier *o*, from which they proceed, diverging to the screen *p q*, where the object will be painted and its apparent size increased.

Professor Amici has constructed a very excellent catoptrical microscope, in which he seems to have avoided the imperfections to which the instruments formerly constructed upon the same principle were liable, and to have combined several advantages which are not possessed by the dioptrical microscopes now in use.

The body of this instrument consists of a horizontal brass tube, twelve inches in length, and one 1-10th in diameter. At one end of the tube is placed a concave speculum of metal, whose axis coincides with that of the tube, and whose superficies is elliptical, and so calculated, that of the two foci, the one falls at the distance of two 6-10ths, and the other at twelve inches from its centre. A thin arm within the tube, carries a small plain mirror of metal of another form, placed at the distance of one 6-10th inches from the former, opposite to it, in an oblique direction, and supported by an oblique section of a metal cylinder 5-10ths of an inch in diameter. The centre of the polished surface of this mirror coincides with the axis of the concave mirror, which is situated at the distance of one 5-10th inches from the centre of the other.

This plain mirror is so placed, that, while it receives the image of the object (which is placed on a moveable object-bearer, attached to the pillar below it) by means of a small aperture in the under part of the body of the tube, it throws it towards the concave mirror, in which it may be examined by the eye of the observer, applied to the opposite end of the tube, through a greater or smaller number of magnifying eye-glasses, which may be fitted to it.

The internal diameter of the tube, which regulates that of the large mirror, may be one 1-10th inches, and the thickness of the surrounding metal about 1-20th. Upon this construction, the object to be examined may always be at the distance of half an inch from the edge of the tube, and consequently be very well lighted on every side; transparent objects, from below, by means of a common illuminating mirror, fitted to the pillar, and moveable; and opaque bodies, from above, either by the natural light falling directly in, or by concentrating an artificial light by means of a convex glass fitted to the object-bearer,—or still better by means of a pierced mirror of metal, which is fitted to the tube below, over the object, so as to be brought more or less near it. The large illuminating mirror below should be concave, having a diameter of three inches, and a focal distance of 2,5 at the utmost.

The effects of the two last-mentioned mirrors may be reciprocally combined, by means of a common corresponding adaptation, by receiving and reflecting the rays of light, so as to produce the highest degree of intensity of light, and the most perfect illumination of the object on all sides, both as a whole, and in its different parts; an advantage, indeed, which can scarcely be attained in dioptrical instruments by similar means.*

A few hints illustrative of the use of this instrument may now be adduced. Whatever object offers itself as the subject of our examination with the microscope, the size and nature of it are first to be considered, in order to examine it with such glasses, and in such a manner, as may show it best. The first step should always be to view the whole of it together, with a magnifier that will take the whole of it in at once; and after this, the several parts of it may the more fitly be examined, whether remaining on the object, or separated from it. The smaller the parts are, the more

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* The following, according to Amici, are the advantages of his microscope.

1. The observer has the convenience of being able to examine the object in a horizontal position, while, in those constructed on the dioptrical principle, the object is examined in a vertical position, that is, from above. Therefore, the observer may be seated, has no occasion to bend his head, and can examine objects more conveniently, or for a longer time, than with a large dioptrical instrument on the common construction.

2. The different degrees of magnifying power can be easily and speedily applied and changed, nothing more being necessary for this purpose than to change the eye-glass, without varying the position or distance of the object, so that it may be examined with great rapidity in all different degrees of magnitude, without the least variation of the point of view; while in the dioptrical instruments, it is not only necessary to change the object-glass, but also the visual distance, which not only occasions loss of time, but very seldom admits of the object being again seen in the same position, and in the same point of view.

3. As in this new instrument the object always remains in the same

powerful ought the magnifiers to be which are employed. The transparency or opacity of the object must also be considered, and the glasses employed, must be selected accordingly; for a transparent object will bear a much greater magnifier than one which is opaque, since the nearness of the eye, when a high magnifier is used, unavoidably darkens an object in its own nature opaque, and renders it very difficult to be seen, unless by the help of an apparatus contrived for that purpose, like Ellis's microscope, with a silver speculum. Most objects, however, become transparent by being divided into extremely thin parts.

The degree of light must always be suited to the object. If that be dark, it must be seen in a full and strong light; but if transparent, the light should be proportionably weak; for which reason there is a contrivance, both in the single and double microscope, to cut off the superabundant rays, when such transparent objects are to be examined with the largest magnifiers. The light of a candle is, for many ob-

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position, and is kept constantly at the distance of half an inch from the body of the microscope, it consequently admits of our examining objects immersed in fluid, and animals swimming, and that nearly at an equal depth, and in every degree of magnitude. With dioptrical instruments, on the other hand, this is quite impossible, on account of the shortness of the focal distance in the highest degrees of magnifying power, as the object-lens must be brought so near the object as almost to come in contact with the fluid.

4. The light may be brought to bear upon all sides, and in all directions, even by means of a lamp or taper, as the flame can be brought very near the illuminating mirror without being troublesome to the observer.

5. As metallic specula do not disperse the light, and consequently producé no colours, the objects appear of their natural colour.

6. The diameter of the concave mirror being so large, compared with its focal-distance, we may expect so much more distinctness.

7. As the distinctness of the image produced by reflection, is greater than that produced by refraction, the degree of magnifying power may be carried much higher.

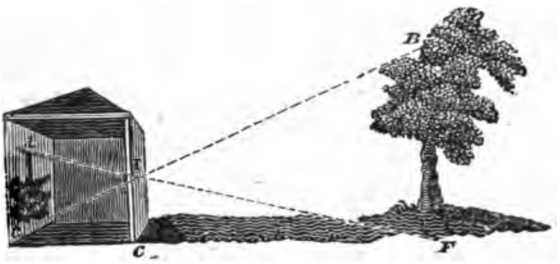
jects, and especially for such as are very bright, transparent, and minute, preferable to daylight; for others, a serene daylight is best: but sunshine is the worst light of all; for it is reflected from objects with so much glare, and exhibits such gaudy colours, that nothing can be determined from it with any certainty. This remark, however, does not extend to the solar microscope; for with that instrument, the brighter the sun shines, the better; as with the solar microscope, we do not see the object itself, on which the sunshine is cast, but only the image or shadow of it greatly extended on a screen; and, therefore, no confusion can arise from the strong reflection of the sun's rays from the object to the eye, as with other microscopes. And with the solar microscope, we must rest contented with viewing the true figure of an object, without expecting to find its natural colour; since no shadow can possibly exhibit the colour of the body which it represents.

Most objects require also some management in order to bring them properly before the glasses. If they are flat and transparent, and such as will not be injured by pressure, the best way is to inclose them between two thin pieces of Muscovy talc, fastened by brass rings in a hole made through a slip of metal or ivory, called a slider. By this means, we may very conveniently preserve the feathers of butterflies, the scales of fishes, and the farina of flowers, as also the parts of insects, the whole bodies of minute ones, and a great number of other objects. Each slider should contain three, four, or more holes, which should not be filled promiscuously; but all the objects preserved in one slider should be such as require the same magnifying power to view them, that there may not be a necessity of changing the glasses for every object; and the sliders should be marked with the number of the magnifier to be used in viewing what it contains. In placing the objects in the sliders, it is proper to have at hand a small magnifier, of about an inch focus, to examine and adjust them by, before they are fixed down by the rings.

The circulation of the blood may be most easily seen in the tails and fins of fishes, in the fine membranes between the toes of a frog, or best of all, in the tail of a water-newt. Such parts of objects of this description, as are intended to be particularly viewed, must be expanded within a glass tube; several sizes of glass tubes usually accompany a microscope, and such a one should be selected as will just admit the object, which will then remain more quiet to be examined.

If fluids come under examination, to discover the animalcula they contain, a small drop is to be taken with a hair-pencil, or on the point of a clean pin, and placed on a plate of glass. If they are too numerous to be thus seen distinctly, some warm water must be added to the drop; they will then separate, and may be seen extremely well. But if a saline solution is to be examined, another method must be resorted to; as the plate of glass must be heated till part of the fluid is evaporated, when the crystals are seen to shoot forth in the most beautiful figures.

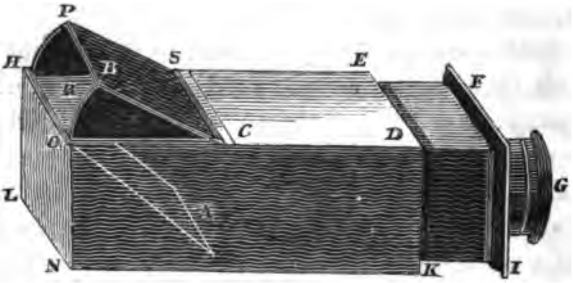
The *camera obscura* is of two sorts. The first and most simple method of exhibiting the images of objects naturally, in a dark chamber, consists in perforating a shutter



with a very minute aperture, and the image of any neighbouring object will be seen on the opposite wall. That it must be inverted, will be evident, from a reference to the section of an apartment in the preceding diagram.

As the lines from the base of the tree F, cannot enter the small hole, it will be evident, that the ray will invert a portion of the image, which will now fall at *d*, while the ray B will be carried down to *c*; a similar effect will also be produced by the passage of the intermediate rays.*

A *portable camera obscura* may also be constructed similar to the annexed figure.



The external box H L O N E D K, has a shutter or cover P B, moving on a hinge S C, and when open, as in the figure, it carries two lateral boards, which serve to exclude the light as much as possible from the rough glass R, placed immediately beneath the shutter P B S C, and upon which the observer is to look. The fore side, or part of the box is wanting, and in that aperture another narrower box E F G I K slides. This box wants the inner side, and has a convex glass lens fixed at G. If this machine be turned with the lens G towards any objects that are well illuminated, it is evident that an inverted picture of these objects will be formed within the box on the side H O L N; and that picture may be rendered distinct by moving the sliding box E F K I in or out, in order to adjust the focus according to the distance of the external objects. Now, at the back part of the box, a flat piece of looking-glass is situated, at an inclination of half a right angle, as is shown by the lines O A; in consequence of which, the rays of light fall upon the looking-glass, and are reflected upwards to the rough glass R, which forms that part of the side of the box which lies under the cover P B S C. The picture then is formed upon that rough, or semitransparent glass, and will appear erect to a spectator situated behind the box, and looking down upon the glass R; because that part of the picture, which falls upon the lower part of the looking-glass, is reflected to the upper part of the rough glass: viz. to the part next the hinge S C, and *vice versa*, as may readily be understood by reference to the figure.

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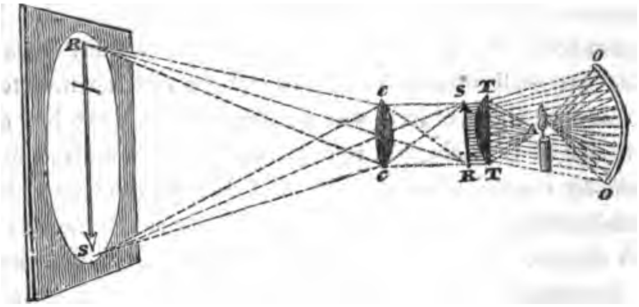
* A very simple experiment, admirably calculated to illustrate this optical deception, may be performed by merely piercing a card with a small pin, and the image of a lamp or candle may then be seen inverted upon a piece of paper placed a little beyond it.

The *magic lantern* may be thus described: let a candle or lamp A, be placed in the inside of a box, so that the light may pass through the plano-convex lens T T, and strongly illuminate the object R S, which is a transparent painting on glass, inverted, and moveable before T T, by means of a sliding piece, in which the glass is set or fixed. The illuminating power of the lamp is materially increased by the reflection of light from a concave mirror *o o*, placed at the other end of the box, which causes the light to fall upon the lens T T, as is shown by the dotted lines in the figure. Lastly, a lens *c c*, fixed in a sliding tube, is brought to the requisite distance from



the object S R, and a large erect image R S is formed upon the opposite wall.

In the common lanterns, the figures are painted on the glass, but all the rest of the glass is left transparent; consequently, the image on the screen is a circle of light, having a figure on it. But in the *phantasmagoria*, all the glass is made opaque, with the exception of the figure, which being painted in transparent colours, the light shines through it: for this reason, therefore, no light can come upon the screen but what passes through the figure itself; consequently, we have upon the screen a figure only, without any circle of light, as in the common magic-lantern. Instead, also, of the representation being made upon a wall or a sheet, as is usually the case, it is thrown upon a thin screen of silk placed between the lantern and the spectator. The appearance of the image approaching and receding, is owing simply to removing the lantern farther from the screen, or bringing it nearer to it: for the size of the image must increase as the lantern is carried back, because the light radiates in the form of a cone; and as no part of the screen can be seen, the figure appears to be formed in the air, and to move farther off when it becomes smaller, and to come nearer as the lantern is carried towards the screen.

The *telescope* was invented about the end of the sixteenth century, and the discovery is commonly supposed to have been casual. The account which is generally received is, that Zacharias Jansen, a spectacle-maker of Magdeburgh, trying the effects of a convex and concave glass united, found that, when placed at a certain distance from each other, they had the property of making distant objects appear nearer to the eye; but the optical laws which led to this result, were not fully examined till the time of Kepler.

The *astronomical telescope* will first claim our notice.* This instrument consists of two convex lenses, A, B, K, M, fig. 1, plate 1, each fixed at the extremity of a different tube. One of the tubes is very short, as its use is merely to adjust the focus in proportion to the distance of the object viewed; and it slides within the other. The tubes are not represented in the figure, as the external form of telescopes is familiar to almost all. Contrary to the arrangement which takes place in the microscope, the glass which has the longest focus is presented to the object, and therefore constitutes the object-glass.

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* A very beautiful analogy between this instrument and the microscope has been drawn by Dr. Chalmers. He says, speaking of the two instruments:—"The one led me to see a system in every star. The other leads me to see a world in every atom. The one taught me that this mighty globe, with the whole burden of its people, and of its countries, is but a grain of sand on the high field of immensity. The other teaches me, that every grain of sand may harbour within it the tribes and the families of a busy population. The one told me of the insignificance of the world I tread upon. The other redeems it from all its insignificance; for it tells me that in the leaves of every forest, and in the flowers of every garden, and in the waters of every rivulet, there are worlds teeming with life, and numberless as are the glories of the firmament. The one has suggested to me, that beyond and above all that is visible to man, there may be fields of creation which sweep immeasurably along, and carry the impress of the Almighty's hand to the remotest scenes of the universe. The other suggests to me, that within and beneath all that minuteness which the aided eye of man has been able to explore, there may be a region of invisibles; and that, could we draw aside the mysterious curtain which shrouds it from our senses, we might there see a theatre of as many wonders as Astronomy has unfolded, a universe within the compass of a point so small, as to elude all the powers of the microscope, but where the wonder-working God finds room for the exercise of all his attributes, where he can raise another mechanism of worlds, and fill and animate them all with the evidences of his glory."

P R represents a very distant object, from every point of which rays come so very little diverging to the object-lens K M of the telescope, as to be nearly parallel: *p r* is the picture of the object P R, which would be formed upon a screen situated at that place. Beyond that place, the rays of every radiant single point proceed divergently to the eye-glass A B of greater convexity, and which causes the rays of each pencil to become parallel, in which direction they enter the eye of the observer at O.

The axes of the two lenses are coincident, in the direction Q L O; L *q* is the focal distance of the object-glass, and E *q* is the focal distance of the eye-glass; consequently, the distance between the two glasses is equal to the sum of their focal distances. An object viewed through this telescope, by an eye situated at O, will appear magnified and distinct, but inverted. The object seen without the telescope, will be, to its appearance through the telescope, as *q* E to *q* L; that is, as the focal distance of the eye-glass to the focal distance of the object-glass. For the pencils of rays, which, after their crossing at *r q p* proceed divergently, fall upon the lens A B, in the same manner as if a real object were situated at *r q p*, and, consequently, after passing through that lens, the rays of each pencil proceed parallel. Now to the eye at O, the apparent magnitude of the object P R is measured by the angle B O A, or by its equal p E r; but to the naked eye at L, when the glass is removed, the apparent magnitude of the object is measured by the angle P L R, or by its equal r L p: therefore the apparent magnitude to the naked eye, is to the apparent magnitude through the telescope, as the angle r L p is to the angle p E r; or as the distance q E is to the distance q L.

If the angles r L p and p E r were equal to each other, the telescope would not magnify; and they would be equal, if the lenses were of equal focal distance. Hence, as the magnifying power of the telescope is produced by making the focal distance of the eye-glass less than that of the object-glass, it will easily be perceived, that the greater the difference of the focal lengths, the greater will be the magnifying power. In practice, however, it is found that they may be so disproportionate, that the increased magnifying power is overbalanced by the indistinctness which ensues. In order, therefore, to obtain a very great magnifying power, with the preservation of just proportion, these telescopes have sometimes been made one hundred feet or upwards in length; and as they were used for astronomical purposes, or mostly in the night-time, they were frequently used without a tube; viz. the object-lens was fixed on the top of a pole, in a frame capable of being moved by a cord or wire in any required direction, and the eye-glass, fixed in a short tube, was held in the hand, or fitted to another frame about the height of the observer, so as to be susceptible of a simultaneous movement.

A telescope of this description was called an *aerial* telescope. Its use is evidently incommodious; but such was the incredible pains taken by philosophers in exploring the wonders which even the imperfect telescopes at first constructed, promised to lay open, that with such an instrument the five satellites of Saturn, and many other remarkable objects, were discovered. The length of common refracting telescopes must be increased in no less a proportion than the square of the increase of their magnifying power; so that in order to magnify twice as much as before, with the same light and distinctness, the telescope must be lengthened four times; and to magnify three times as much, nine times. On this account, their unwieldy length, when great powers are desired, is unavoidable.

The breadth of an object-glass adds nothing to the magnifying power; for whatever it may be, the image will be equally formed at the distance of its focal length; but the brilliancy of the image will be increased by the breadth, as a greater number of rays will then diverge from every point of the image.

The magnifying power, and the field of view, in this telescope may be increased by using two plano-convex lenses, combined so as to act like one glass; and such a combination is now generally employed. The disproportion above alluded to, which may subsist between an object-glass and an eye-glass, arises from this circumstance, that a lens does not converge the rays of the same radiant point, exactly to the same refracted focus, and the indistinctness, which is thus occasioned in the image, increases with the thickness of the lens, and the increase of its curvature. Hence arises the limitation to the use of highly magnifying eye-glasses. The field of view is enlarged by enlarging the eye-glass; but if a lens of very short focus were made large, the irregularity of its refraction would throw the view into confusion; if it were made sufficiently small to prevent this, it would be equally useless from its contracted field of view, and the want of light. But if two plano-convex lenses be used, the curvature of both conjointly will be less than the curvature of a single lens of equally magnifying power; such a combination, therefore, will improve the eye-glass of a telescope, because the aberration of the rays passing through it will be less than through a single lens of the same focus.

The *astronomical telescope*, by the use of two additional eye-glasses, shows objects in their right position, and becomes a terrestrial telescope, that is, adapted for looking at objects on the earth. It is still more frequently called a perspective glass. This telescope is shown at fig. 2, plate 1. The rays of each pencil coming from the image L M of the object I K, emerge parallel from the lens A B, and having crossed at its focus, O, they continue in that direction to the lens E F, in consequence of which they form an image S T at the focus of the second lens, and again diverging, they fall upon the third lens, C D, in the same manner as they did upon the lens A B; therefore, after their emergence from this last lens, they fall parallel upon the eye at G. But as the last image, S T, is not inverted as at L M, but in the same position as the object I K, the eye sees a true or upright picture, as if the rays had come directly from the object.

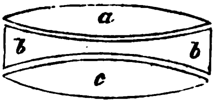
Galileo's Telescope consists of a convex object-glass, and a concave eye-glass, as represented by fig. 3, plate 1. The distance between the two lenses is less than the focal distance of the object-glass; but the concave glass is situated so as to make the rays of each pencil fall parallel upon the eye, as is evident by conceiving the rays to go back again through the eye-glass, towards O; E O being the focal length of the eye-glass.

When the sphere of concavity in the eye-glass of a Galilean telescope is equal to the sphere of convexity in the eye-glass of another telescope, their magnifying power is the same; but the concave glass being placed between the object-glass and its focus, the Galilean telescope will be shorter than the other, by twice the focal length of the eye-glass. Hence, if the lengths of the telescopes be the same, the Galilean will have the greatest magnifying power.

Having already seen that the coloured rays forming the prismatic spectrum, differ in refrangibility, it will be quite evident that the nearer a lens approaches to the form of a prism, the more unequal must its refractive power be. It will, however, be apparent, by a reference to the figures shown in the prismatic spectrum, that every convex lens partakes of this defect, and it is on this account that the extremities of objects, viewed through them, are invariably found to be tinged with coloured rays; for the rays having different foci, will form their respective images at different distances from the glass. This defect in the construction of the telescope was at first considered as a necessary concomitant to all instruments in which great magnifying power was required; and Sir Isaac Newton, who first suggested the practicability of employing a compound lens, appears to have been too much absorbed by other pursuits to mature an arrangement of that description. The same result was attempted by Euler, who recommended a double object glass, consisting of two lenses, with water between them.

The published memoir of the Swiss philosopher excited the attention of Mr. Dollond, an optician of considerable celebrity; who, trying the refractive power of water, combined with glass, in the form of a prism, ascertained that a series of glasses with different refractive powers would produce a similar effect.

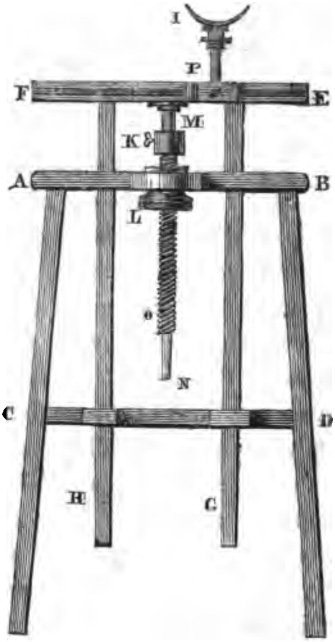
The object-glasses of Dollond's telescopes are composed of three distinct lenses, two of which are convex, and the other concave. The concave one is by British artists, placed in the middle, as represented in the accompanying figure, where *a* and *c* show the two convex lenses, and *b b* the concave one. The two convex ones are made of London crown glass, and the middle one of white flint-glass, and they are all ground to spheres of different radii, according to the refractive powers of the different kinds of glass, and the intended focal distance of the object-glass of the telescope. According to Boscovich, the focal distance of the parallel rays for the concave glass is one-half, and for the convex-glass one-third of the combined focus.



In instruments where only a small magnifying power is required, and in cases in which it would be difficult to introduce the compound achromatic glass of Dollond, Dr. Brewster suggests the use of a variety of substances, consisting principally of essential oils, which are made to form achromatic combinations by means of single lenses, when employed as in the annexed list.

Substances fit for Eye Glasses.	Substances fit for Object Glasses.
Glass of lead.	Crown glass.
Oil of casia	Plate glass.
Oil of anise seeds.	Water.
Oil of cummin.	Alcohol.
Oil of cloves.	Sulphuric acid.
Oil of sassafras.	Oil of ambergrease.
Oil of sweet fennel seeds.	Rock crystal.
Oil of spearmint.	Topaz.

In supporting the large refracting telescope, some contrivance is necessary, to enable the observer to facilitate the motion of the instrument. Indeed, it requires to be supported at both ends, and then the nearer support must have adjustments for both altitude and azimuth, while the remote one may be a point of rest.



The accompanying diagram shows a support for the eye-end of a long telescope, which was originally contrived by Smeaton, and which is well calculated for its intended purpose. A B C D is a mahogany frame, four feet six inches high; the cross piece A B is fifteen inches long, and the piece C D seventeen, at the distance of eighteen from the other; another frame E F G H, with parallel sides, nine inches apart, and more slender than the other frame, passes through the cross-bars of the former, in such a way as to have an easy motion; a cylinder or rod of brass is screwed by its head-piece to the cross-bar E F, and descends from M to N, through a wooden screw L O, which is hollow within, and cut into a screw round its circumference: this wooden screw terminates above with a brass socket and thumb-screw, which acts as a screw of pressure against the interior brass rod; the thick wooden piece L has a female screw, acting with the male screw of the hollow wooden cylinder L O, but is so made fast to the cross-bar A B, by a circular plate of brass above, that though it will turn round, it will neither ascend nor descend; consequently, will produce an ascending or descending motion in the wooden cylindrical piece L O, and also in the brass rod M N, held by the screw K, attached to it. The concave piece of brass I, has two motions in its stem, one horizontal, and the other vertical, like those in the stem of a small telescope, and receives the eye-end of a long telescope, to which it is screwed, while the remote end is supported by the branch of a tree, the block of a pulley, an opening in the roof of a house, or other elevated part of a building. The adjustments are thus managed: when the elevated end of the telescope is made to rest on its bearer, the eye-end adapts itself to the inclination by the joint in its stem under I; then the whole frame is turned to face the object, when the circular motion of the same small stem yields, and allows the long tube to remain quiet; and if the tube is not exactly pointed in azimuth to the object, the brass piece F, into which the stem I is made fast, slides along a groove made in the front face of the cross-bar E F, until the adjustment for azimuth is complete. This sliding motion, being manual, may be either quick or slow, as the observer desires;

therefore, when a body in motion is once in the field of view, it may be followed without difficulty, by pushing the sliding-piece P in a proper direction. The quick and slow motions for adjustment in altitude are separate, and are thus produced: first, the thumb-screw K is turned back, so as to let the rod M N ascend freely, till the altitude is nearly right, when it is fixed, and then the piece L is turned, backward or forward, as the case may require, with the right hand, while the left slowly slides the piece P, until the object is in the middle of the field; and when distinct vision has been properly obtained by the small tube at the eye-piece of the telescope, the pieces L and P, held respectively in each hand, will always afford the means of keeping the object in the proper part of the field; and though the support has but two legs, yet its connection with the support at the object end, through the heavy tube of the telescope, will always keep it in its place when the adjustments are settled.

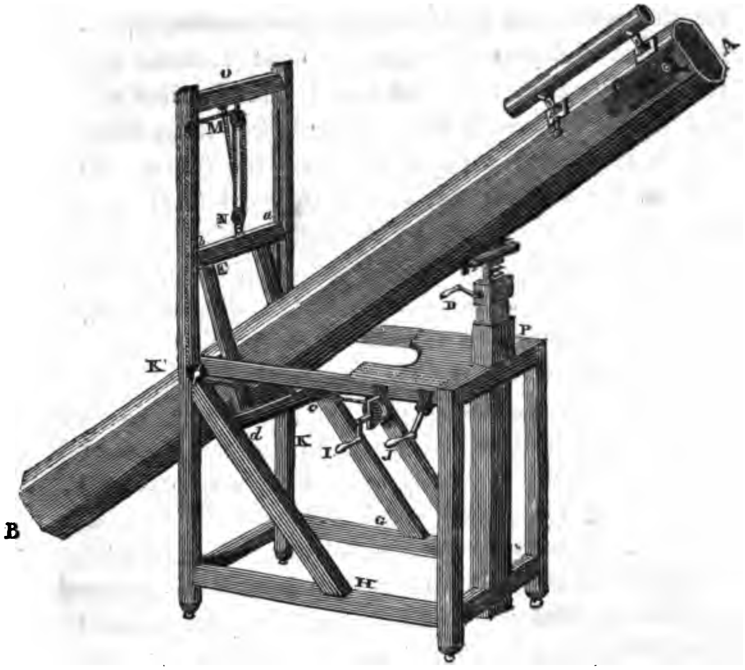
We come now to the *reflecting telescope.* Mathematicians had demonstrated, that a pencil of rays could not be collected in a single point by a spherical lens; and also, that the image transmitted by such a lens would be in some degree incurvated. Gregory, a young man of great abilities, was induced to believe that these inconveniencies, and also the great length of the refracting telescopes, would be obviated by substituting for the object-glass of the common telescope, a metallic speculum, of a parabolic figure, to receive the image, and to reflect it towards a small speculum of the same metal. This again was to return the image to an eye-glass placed behind the great speculum, which, for that purpose, was to be perforated in its centre. These ideas were published by Gregory in 1663, but, as he possessed no mechanical dexterity himself, and could find no workman capable of realizing his invention, it might have sunk into oblivion, had not Sir Isaac Newton, in the course of his discoveries, found that the errors arising from the different refrangibility of light were incomparably greater than those arising from reflection; and being himself as remarkable for manual skill, as mathematical knowledge, he was independent of others for the execution of his design. He therefore determined to try what could be done, and executed two reflecting telescopes in 1672, on a plan somewhat different to what Gregory had proposed. Although a good metal for the speculum was not then known, although he had to contrive for himself the method of polishing it, and although his telescopes were but six inches long, yet in power they were quite equal to a six-feet reflector, and were capable of showing Jupiter's satellites.

One great advantage of the reflecting telescope is, that it will admit of an eye-glass of a much shorter focal distance than a refracting telescope of the same length; consequently, it will magnify so much the more. This advantage arises principally from the rays of light not being dispersed by reflection as they are by refraction, and partly from the practicability of giving the large reflectors a form either parabolical, or at least, such as answers better than the spherical figure.

The theory of *Gregory's telescope* may be first examined. Plate I, fig. 4, represents a section of this instrument as it was originally made; fig. 5, being the improved form; in both which we may use the same letters of reference to the corresponding parts. A B C D, in each figure, denote the tube of wood or brass, in which two concave specula are contained; the large one, B D, is perforated at the centre, and placed contiguous to the interior end of the tube, but in such a way as to have a little play when pressed by a circular spring behind it; E F is the small speculum, which is of shorter radius than the speculum B D, and has its centre placed exactly in the centre of the tube opposite the central aperture in the large speculum, and is so adjusted by the screws behind it, that the image of the large speculum forms a concentric circle on its reflecting surface, when viewed by an eye situated in the central hole of the large speculum. In this instrument, as in the refracting telescope, it will be most convenient to describe first the formation of the primary image of a distant object in the body of the tube, and then the microscopic means applied for rendering this image visible in an apparently magnified state; for in truth there is actually a compound reflecting microscope made use of as a constituent part of this instrument, in the same manner as the terrestrial tube of a refracting telescope of the best achromatic construction, is in itself a compound refracting microscope. In the first place, agreeably to the laws of catoptrics, if we consider *a b* and *c d* two rays of light coming from the centre of a distant arrow in a state of divergence approaching to parallelism, and impinging on the large speculum at the point *b* and *d*, near the remote edges of the speculum, and at equal distances from its axis, they will be reflected inwardly, so as to meet at the point *e*, in the common axis of both the specula, and will form the image of the central point of the arrow; and in like manner, any number of rays proceeding from the opposite ends of the said arrow, may be conceived to fall on the speculum, and to be reflected to the points *h* and *i*, and to all the intermediate points, so as to form a perfect image *h e i*, in an inverted position, because the rays which enter the tube from the right-hand end of the arrow, will, after reflection, cross the axis, and form the left-hand end of the image, and *vice versa*. When an image is thus formed, if it could be viewed, under sufficiently favourable circumstances, by an eye placed in the vertex or central aperture of the large speculum, it would subtend the same angle as the object itself seen from the same situation, as we have already demonstrated; and, therefore, the length of the image will bear the same proportion to the length of the object which it represents, as its distance from the eye, or vertex, is to that of the object; so that the longer the radius of the speculum which forms the image, the more distant, and, consequently, the longer will this image be, as compared with the object; and for the same reason, the nearer the object, the longer will its image be, until the situation is at the centre of concavity of the speculum, where the object and image will coincide, and appear of like magnitude, but in contrary positions.

This formation of the primary image being understood, we must in the next place consider it as a real microscopic object, placed somewhere between the face of the large speculum and its centre of concavity: which situation will always depend on the distance of the real object itself, or, which is the same thing, on the degree of divergence of the incident rays coming from the object. Now, if the small speculum were so placed, as to have this primary image, or microscopic object, in its solar focal point, the rays coming from it would be reflected towards the large speculum in a parallel state; and passing through the central opening of the large speculum, would never converge so as to form a primary image, in which case the conjugate focus would be said to be *infinite*: and if the said primary image were nearer to the small speculum than its solar focus, the reflected rays would diverge, so as not to reach the central hole of the large speculum at all; but if the distance of the primary image *h e i*, exceeds the solar focus of the small speculum E F, which is at the point *f*, then the reflected rays coming from the primary image, will converge to a conjugate focus somewhere in the axis, and form a *secondary* image, the magnitude of which will increase with its distance from the primary image, which we now consider as a real microscopic object. The place where this secondary image will fall, will depend on the distance of the primary image from the solar focus of the small speculum; and a small change of this distance will cause a great corresponding change in the place of the secondary image, or conjugate focus; so that an adjustment for a small forward and backward motion of the small speculum, by means of a screw at the end of a long rod placed parallel to the tube, and reaching to the eye-end, will suffice for regulating the place where the secondary image shall most conveniently fall to be viewed by an eye-glass. The secondary image has its position reversed, as it regards the primary one, and is therefore in the same position as the object itself, or what is usually called *erect*, in opposition to *inverted*. This secondary image was originally made to fall within the tube, as at *k l* in the focus of the eye-glass G H, through which it may be viewed by a small hole at I, where the visual angle G I H is now considerably enlarged.

The best arrangement for the Newtonian reflecting telescope is shown on the next page. A telescope of this description forms part of the valuable apparatus in the London Institution. A, is the elevated mouth of the tube, and B, the place of the large speculum, that reflects the rays of light back to the small diagonal plane metal near C, which, by a second reflection, brings them to a focus at the eye-piece below C, as seen in the engraving. Above C, is the finder, the upper end of which has a small achromatic



object-glass, and the lower end the eye-glass. The upper end of the tube rests on a support D, that is capable of being raised or lowered slowly, by a pinion on the axis of the handle under D, while the lower end rests on the horizontal bar of the frame F, that is suspended by a pulley over F; the four pivots *a*, *b*, *c*, and *d*, of the said frame, sliding in the open grooves, seen near those letters, in the main frame, keep the small frame in any given situation, and allow a free motion, first down the vertical, and then down the inclined pieces, that compose the main frame, as low as to G and H; and when the lower end of the tube has been depressed into this situation, the tube may have an elevation approaching towards the zenith: for not only is the upper end elevated by the handle at J for the quick, and at D for the slow motions, but the lower one is depressed by the handle at I, round which the cord is coiled, that goes round a fixed collar at K, and two others at M, before it embraces the pulley N, and is hooked to a pin at O, above the frame. The rest of the main frame is so clearly exhibited in the engraving, that no farther description of it is necessary. In some of the instruments of this construction, when the handle J is omitted, and a quicker motion in altitude is required, and also a greater elevation than can be given simply by the handle at D, the second square stem that carries the pinion of the handle is raised by hand, and kept to its elevation by means of a second rack, which is set at liberty by pressing a button at P, connected with the spring-catch of the rack, when this squared stem is lowered again: all which motions will be readily comprehended by any person tolerably acquainted with the mechanism of rack-work. The quick motion in azimuth is given by sliding the lower end of the tube gently along the bar on which it rests, or by moving the whole frame, which moves on castors; but the slow motion is produced by the screw at D. It is scarcely necessary to add, that the eye of the observer is applied to the side of the tube near its mouth, when the finder has pointed the tube properly to its object.

In 1781, Sir William (then Dr.) Herschel began a thirty-feet aërial reflector; but his mirror, thirty-six inches in diameter, having at one time cracked in the cooling, and at another period run into the fire, from a failure in the furnace, his project was partially abandoned. But the plan for forming a telescope of extraordinary size having been submitted by Sir Joseph Banks to the King, His Majesty offered to defray the expense of it, and, under his patronage, this distinguished optician began, about the end of the year 1785, to construct a telescope of forty feet in focal length. This splendid instrument, which magnifies 6450 times, was completed on the 27th of August 1789; and on the day following, Dr. Herschel discovered a new satellite belonging to the planet Saturn.*

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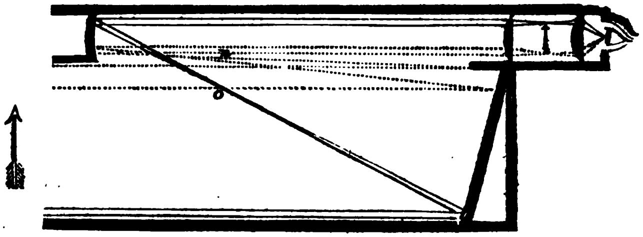
* The tube of this gigantic telescope is made of rolled, or sheet-iron, the thickness of the sheets being somewhat less than a 36th part of an inch. Great care was taken in so joining the plates of which the tube is composed, together, that the cylindrical form should be secured, and then the whole was coated over three or four times with paint, inside and outside, to secure it against the damp. The tube was formed at a short distance from its present situation, and removed with great ease by twenty-four men, divided into six sets; so that two men on each side, with a pole of five feet long in their hands, to which was affixed a piece of coarse cloth, seven feet long, going under the tube, and joined to a pole of five feet long, in the hands of two other men, assisted in carrying the tube. The length of the tube is 39 feet 4 inches, the diameter 4 feet 10 inches; and, upon a moderate computation, it is supposed that a wooden tube for the same purpose would have exceeded this in weight by at least 3000 pounds. The length of the iron plate forming the tube, and composed of smaller ones, 3 feet 10 inches long, and 23½ inches broad, is nearly 40 feet, and the breadth 15 feet 4 inches.

The great mirror is made of metal, 49½ inches in diameter; but the concave part, or polished surface, is only 48 inches in diameter. Its thickness is 3½ inches; and, when it came from the mould, its weight was 2118 pounds, of which a small quantity must have been lost in polishing. An iron ring, 49½ inches in diameter, within, 4 inches broad, and 1½ thick, with three strong handles to it, goes round the mirror, and a flat cover of tin is made to correspond to this ring, that the mirror may be preserved from damp; and, by an easy contrivance, it is taken off and fixed on at pleasure.

At the upper end, the tube is open, and directed to the part of the heavens intended for observation, to which the observer's back is turned, and he, standing on the foot-board, looks down the tube, and perceives the object, by rays reflected from the great mirror, through the eye-glass at the opening of the tube. Near the place of the eye-glass is the end of a tin pipe, into which a mouth-piece may be placed; so that, during an observation, a person may direct his voice into this pipe, whilst his eye is at the glass. This pipe is 1½ inch in diameter, A new form of the telescope may here be briefly noticed; it is represented beneath.



The great mirror is, as usual, at the bottom of the principal tube, but instead of having its axis coincident with that of the tube, it is inclined, so as to throw the image upwards, through an aperture for that purpose, to *n o*,

runs down to the bottom of the tube, where it goes into a turning joint, thence into a drawing tube, and out of this into another turning joint, from whence it proceeds by a set of sliding tubes towards the front of the foundation timber. The use of this tube is to convey the voice of the observer to his assistants; for, at the last place, it divides itself into two branches, one going into the observatory, the other into the workman's room, ascending in both places through the floor, and being terminated in the usual shape of speaking-trumpets. Though the voice passes in this manner, through a tube with many inflections, and not less than 115 feet, it requires very little exertion to be well understood.

To direct so immense a body to any part of the heavens at pleasure, much ingenuity, and many mechanical contrivances are evidently necessary. The whole apparatus rests upon rollers, and care was previously taken of the foundation in the ground. This consists of concentrical circular brick walls, the outermost 42 feet, the innermost 21 feet in diameter; 2 feet 6 inches deep under ground, 2 feet 3 inches broad at the bottom, and 1 foot 2 inches at the top, capped with paving stones, about 3 inches thick, and 12¾ inches broad. In the centre is a large post of oak, framed together with braces under ground, and walled fast with brick-work, to make it steady. Round this centre, the whole frame is moved horizontally, by means of twenty rollers, twelve upon the outer, and eight upon the inner wall.

whence the rays diverge, and falling upon the small speculum, are reflected by it to the eye, as in the Gregorian telescope. Here we have supposed the small mirror to be concave, but that is not the form invariably resorted to, as it is clear, that the same principle is preserved, if the whole diameter of the mirror is employed to reflect light; and, therefore, it may have the small mirror convex, like Cassegrain's reflector, or plane, like Newton's.

The two mirrors of a telescope should not have precisely the same curve. Maskelyne has observed, that when the two specula are parabolas, they cause a very considerable aberration, which is negative, that is to say, the focus of the extreme ray is longer than those of the middle ones. If the large speculum is a parabola, the small one ought to be an ellipse; but when the small speculum is spherical, which is generally the case in practice, if concave, the figure of the large speculum ought to be an hyperbola; if convex, the large speculum ought to be an ellipse, to free the telescope from aberration. This will be easier understood, by attending to the positions of the first and second images; when a curve is of such a form, that lines drawn from each image, and meeting in any point of the curve, make equal angles with the tangent to the curve at that point, it is evident that such curve will be free from aberration.

The following observations on a very important adjustment, of which telescopes ought to be susceptible, are furnished by Mr. Nicholson. "Every attentive observer must have taken notice, that light is of as much consequence to artificial vision as magnifying power. It may therefore, afford matter of surprise, that the most variable of all adjustments of the eye, viz. that of aperture, should never be introduced into our artificial combinations. Distant woods, and other land objects, are invisible to a high magnifying power, for want of light; when the same object may be distinctly seen with a lower. By means of an artificial iris, which an ingenious artist will find little difficulty in contriving, this disadvantage in telescopes might be obviated. Suppose a brass ring to surround the object end of the telescope, and upon this, let eight or more triangular slips of brass be fixed, so as to revolve on equi-distant pins, passing through each triangle near one of its corners. If the triangles be slidden in upon each other, it may readily be apprehended, that they will close the aperture; and if they be all made to revolve or slide backwards alike, it is clear, that their edge will leave an octagonal aperture, greater or less according to circumstances. The equable motion of all the triangles may be produced either by pinions and one-toothed wheel, or by what is called snail-work. Another kind of iris, more compact, may be made by causing thin elastic slips of brass to slide along, parallel to the tube, and be conducted through a slit in a brass cap, which will lead them across the aperture in a radial direction.

The *micrometer* is an important part of the telescopic apparatus, and as such, must not be passed unnoticed.

Mr. Ramsden has described two valuable micrometers, which he contrived, with the view of remedying the defects of those that had been previously constructed. One of these is a catoptric micrometer, and can have no aberration, nor is it liable to any defect arising from the imperfection of its materials, or execution: as the extreme simplicity of its construction requires no additional mirrors or glasses to those required for the telescope; and the separation of the image being effected by the inclination of the two specula, and not depending on the focus of any lens or mirror, any alteration in the eye of an observer cannot affect the angle measured. It has also the advantages of an adjustment, to make the images coincide in a direction perpendicular to that of their motion; and also of measuring the diameter of a planet on both sides of the zero, which is of no small advantage to observers, who know how much easier it is to ascertain the contact of the external edges of two images, than their perfect coincidence. A, Plate I, fig. 6, represents the small speculum of a reflecting telescope, of Cassegrain's construction, to which this micrometer is adapted, divided into two equal parts; one of which is fixed on the end of the arm B; the other end of the arm is fixed on a steel axis X, which crosses the end of the telescope C. The other half of the mirror A is fixed on the arm D, which arm at the other end terminates in a socket *y*, that turns on the axis X; both arms are prevented from bending by the braces a a. G represents a double screw, having one part, *e*, cut into double the number of threads in an inch to that of the part *g*; the part *e*, having a hundred threads in one inch, and the part *g* fifty only. The screw, *e*, works in a nut F, in the side of the telescope, while the part *g*, turns in a nut H, which is attached to the arm B; the ends of the arms B and D, to which the mirrors are fixed, are separated from each other by the point of the double screw pressing against the stud *k*, fixed to the arm D, and turning in the nut H on the arm B. The two arms B and D, are pressed against the direction of the double screw, *e g*, by a spiral spring within the part *n*, by which means all shake or play in the nut H, on which the measurement depends, is entirely prevented.

From the difference of the threads on the screw at *e* and *g*, it is evident that the progressive motion of the screw through the nut will be half the distance of the separation of the two halves of the mirror, and, consequently, the half mirrors will be moved equally in contrary directions from the axis of the telescope C.

The wheel V, fixed on the end of the double screw, has its circumference divided into 100 equal parts, and numbered at every fifth division, with 5, 10, &c. to 100; and the index, I, shows the motion of the screw with the wheel round its axis, while the number of revolutions of the screw is shown by the divisions on the same index. The steel screw, R, may be turned by the key S, and serves to incline the small mirror at right angles to the direction of its motion.

The other micrometer, invented and described by Mr. Ramsden, is suited to the principle of refraction. This micrometer is applied to the erect eye-tube of a refracting telescope, and is placed in the conjugated focus of the first eye-glass; in which position, as the image is considerably magnified before it comes to the micrometer, any imperfection in its glass will be magnified only by the remaining eye-glasses, which in any telescope seldom exceeds five or six times; and besides, the size of the micrometer glass will not be the hundredth part of the area which would be required, if it were placed at the object-glass; and yet the same extent of scale is preserved, and the images are uniformly bright in every part of the field of the telescope. This micrometer is represented at fig. 7 in the same plate. A, is a convex or concave lens, divided into two equal parts by a plane across its centre; one of these semi-lenses is fixed in a frame B, and the other in the frame E, which two frames slide on a plate H, and are pressed against it by thin plates, *a a*; the frames B and E are moved in contrary directions by turning the button D; L is a scale of equal parts on the frame B; it is numbered from each end towards the middle with 10, 20, &c. There are two verniers on the frame E, one at M, and the other at N, for the conveniency of measuring the diameter of a planet, &c. on both sides of the zero. The first division on both these verniers, coincides at the same time with the two zeros on the scale L; and, if the frame is moved towards the right, the relative motion of the two frames is shown on the scale L by the vernier M; but if the frame B be moved towards the left, the relative motion is shown by the vernier N.

This micrometer has a motion round the axis of vision, for the conveniency of measuring the diameter of a planet, &c. in any direction, by turning an endless screw F; and the inclination of the diameter measured with the horizon, is shown on the circle *g*, by a vernier on the plate V. The telescope may be adjusted to distinct vision by means of an adjusting screw, which moves the whole eye-tube with the micrometer, nearer or farther from the object-glass, as telescopes are generally made; or the same effect may be produced in a better manner, without moving the micrometer, by sliding the part of the eye-tube *m*, on the part *n*, by the help of a screw or pinion. The micrometer is made to take off occasionally from the eye-tube, that the telescope may be used without it.

Sir William Herschel applied a lamp-micrometer to Sir Isaac Newton's reflecting telescope. Two moveable lamps, the light of which is made to pass through two small holes, are placed at a convenient distance from the telescope, in the direction at which the observer looks at the image. These points of light are observed by the left eye, and brought to the opposite sides of a planet which comes within the sphere of vision of the right eye; and by measuring their distance from each other, and from the eye, the angle under which the magnified diameter appears will be known, which, divided by the magnifying power of the telescope, gives the apparent diameter required. The construction of this micrometer is as follows: A B G C F E, fig. 8, Plate I. is a stand nine feet high, upon which a semicircular board, *q h o g p*, is moveable upwards or downwards, in the manner of some fire-screens, as occasion may require; and is held in its situation by a peg *p*, put into any one of the holes of the upright piece A B. This board is a segment of a circle, of fourteen inches radius, and is about three inches broader than a semicircle, to give room for the handles *r* D, *e* P, to work. The use of this board is to carry an arm L, thirty inches long, which is made to move upon a pivot at the centre of the circle by means of a string, which passes in a groove upon the edge of the semicircle *p g o h q*; the string is fastened to a hook at *o*, (not expressed in the figure, being at the back of the arm L,) and passing along the groove from *s h* to *q*, is turned over a pulley at *q*, and goes down to a small barrel *e*, within the plane of the circular board, where a double-jointed handle, *e* P, commands its motion. By this contrivance, we see the arm L may be lifted up to any altitude from the horizontal position to the perpendicular, or be suffered to descend by its own weight below the horizontal to the reverse perpendicular situation. The weight of the handle, P, is sufficient to keep the arm in any given position; but if the motion should be too easy, a friction-spring applied to the barrel will increase the friction at pleasure.

In front of the arm, L, a small slider, about three inches long, is moveable in a rabbet from the end L towards the centre, backwards and forwards. A string is fastened to the left side of the little slider, and goes towards L, where it passes round a pulley at *m*, and returns under the arm from *m n*, towards the centre, where it is led in a groove on the edge of the arm, which is of a circular form, upwards to a barrel (raised above the plane of the circular board) at *r*, to which the handle, *r* D, is fastened. A second string is fastened to the slider, at the right side, and goes towards the centre, where it passes over a pulley *n*, and the weight *w*, which is suspended by the end of this string, returns the slider towards the centre, when a contrary turn of the handle permits it to act.

a and *b* are two small lamps, two inches high, one inch and a half in breadth by one inch and a quarter in depth. The sides, back, and top, are made so as to permit no light to be seen; and the front consists of a thin brass sliding door. The flame in the lamp, *a*, is placed three-tenths of an inch from the left side, three-tenths from the front, and half an inch from the bottom. In the lamp *b*, it is placed at the same height and distance, measuring from the right side. The wick of the flame consists only of a single very thin lamp-cotton thread; for the smallest flame being sufficient, it is easier to keep it burning in so confined a place. In the top of each lamp must be a little slit, lengthways, and also a small opening in one side near the upper part, to permit air enough to circulate to feed the flame. To prevent every reflection of light, the side opening of the lamp *a*, should be to the right, and that of the lamp *b*, to the left. In the sliding door of each lamp is made a small hole, with the point of a very fine needle, just opposite the place where the wicks are burning, so that when the sliders are shut down, and every thing dark, nothing shall be seen but two fine lucid points of the size of two stars of the third or fourth magnitude. The lamp *a*, is placed so that its lucid point may be in the centre of the circular board, where it remains fixed. The lamp *b*, is hung to the little slider, which moves in the rabbet of the arm, so that its lucid point in a horizontal position of the arm, may be on a level with the lucid point in the centre. The moveable lamp is suspended upon a piece of brass, fastened to the slider by a pin, exactly behind the flame upon which it moves as a pivot. The lamp is balanced at the bottom by a leaden weight, so as always to remain upright, when the arm is either lifted above, or depressed below, the horizontal position. The double-jointed handles, *r* D, *e* P, consist of light deal rods, ten feet long, and the lowest of them may have divisions, marked upon it near the end P, expressing exactly the distance from the central lucid point, in feet, inches, and tenths.

From this construction we see, that a person at a distance of ten feet may govern the two lucid points, so as to bring them into any required position south or north, preceding or following from 0 to 90°, by using the handle P; and also to any distance from six-tenths of an inch, to five, or six and twenty inches, by means of the handle D. If any reflection or appearance of light should be left from the top or sides of the lamps, a temporary screen, consisting of a long piece of pasteboard, or a wire-frame covered with black cloth, of the length of the whole arm, and of any required breadth, with the slit of half an inch broad in the middle, may be affixed to the arm by four bent wires, projecting an inch or two before the lamps, situated so that the moveable lucid point may pass along the opening left for that purpose.

Fig. 9, represents part of the arm L, half the real size; S, the slider; *m*, the pulley over which the cord *x t y z*, is returned towards the centre; *v*, the other cord going to the pulley *n*, of fig. 10; R, the brass piece, moveable upon the pin *c*, to keep the lamp upright. At R, is a wire rivetted to the brass piece, upon which is held the lamp, by a nut and screw. Figs. 11 and 12, represent the lamps *a*, *b*, with the sliding doors open, to show the situation of the wicks. W, is the leaden weight, with a hole, *d*, in it, through which the wire, R, is to be passed, when the lamp is to be fastened to the slider S. Fig. 13, represents the lamp *a*, with the sliding door shut; *l*, the lucid point; and *i k*, the openings at the top, and *s*, at the sides, for the admission of air.

Cavallo's micrometer is simple and valuable. It consists of a small semi-transparent scale, or slip of mother-of-pearl, about the twentieth part of an inch broad, and of the thickness of common writing-paper. It is divided into a number of equal parts, by means of parallel lines, every fifth and tenth of which divisions is a little longer than the rest.

This micrometer, or divided scale, is situated within the tube, at the focus of the eye-lens of the telescope, where the image of the object is formed, and with its divided edge passing through the centre of the field of view, though this is not absolutely necessary. It is immaterial whether the telescope be a refractor or a reflector, provided the eye-lens be convex, and not concave, as in the Galilean telescope.

The simplest way of fixing it is to stick it upon the diaphragm, which generally stands within the tube, at the focal distance of the eye-lens. By looking through the telescope, the image of the object and the micrometer will appear to coincide; hence, the observer may easily see how many divisions of the latter measure the length or breadth of the former; and knowing the value of the divisions of the micrometer, he may easily determine the angle which is subtended by the object.*

The mother-of-pearl micrometer may be applied to a microscope, and it will thus serve to measure the lineal dimensions of the object. The value of its divisions may be ascertained by placing an object of a known dimension before the microscope, and by observing how many divisions of the micrometer measure its magnified image. For instance, place a piece of paper, which is exactly one-tenth of an inch long before the microscope, and if it is found that 50 divisions of the micrometer measure its magnified image, the observer may conclude that each division denotes an extension of the 500th part of an inch in the object; for if 50 divisions measure 1-10th, 500 divisions must measure the whole inch.

Mother-of-pearl was found, by Cavallo, after many trials, to be a much more convenient substance than either glass, ivory, horn, or wood, as it is a very steady substance, the divisions are easily marked upon it, and when made as thin as common writing-paper, it has a very useful degree of transparency.

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[*] There are several methods of ascertaining the value of the divisions of a micrometer in a given telescope. The following is one of the easiest: direct the telescope to the sun, and observe how many divisions of the micrometer measure its diameter exactly; then take out of the Nautical Almanack the diameter of the sun for the day in which the observation is made; divide it by the above-mentioned number of divisions, and the quotient is the value of one division of the micrometer. Thus, suppose that 26½ divisions of the micrometer measure the diameter of the sun, and the Nautical Almanack gives for the measure of the angle which is subtended by the same diameter, 31′.22″; or (by reducing the whole into seconds) 1882 seconds. Divide 1882 by 26.5, and the quotient neglecting a small remainder, is 71″, or 1′.11″; which is the value of one division of the micrometer; and, therefore, the value of any greater number of divisions is easily ascertained.

Scientific men have often had occasion to regret the difficulty of procuring fibres sufficiently elastic for micrometers. The difficulty of obtaining silver wire of a diameter small enough, induced Mr. Troughton to use the spider's web, which he has found so fine, opaque, and elastic, as to answer all the purposes of practical astronomy. But as it is only the stretcher, or long line, which supports the web, that possesses these valuable properties, the difficulty of procuring it has compelled many opticians and practical astronomers to employ the raw fibres of unwrought silk, or what is still worse, the coarse silver wire manufactured in this country. For these, Dr. Brewster has succeeded in obtaining a substitute, in a delicate fibre, which enables the observer to remove the error of inflection, while it possesses the requisite properties of opacity and elasticity. This fibre is made of glass, which is so exceedingly elastic, that it may be drawn to any degree of fineness, and can always be procured and prepared with facility. This vitreous fibre, when drawn from a hollow tube, will always be of a tubular structure, and its interior diameter may always be regulated by that of the original tube. When such a fibre is formed, and stretched across the diaphragm of the eyepiece of a telescope, it will appear perfectly opaque, with a delicate line of light extending along its axis. As this central transparency arises from the transmission of the incident light through the axis of the hollow tube, and this tube can be made of any calibre, the diameter of the luminous streak can be either increased or diminished. In a micrometer fitted up in this way by Dr. Brewster, the glass fibres are about 1-1200th of an inch in diameter; and the fringe of light is distinctly visible, though it does not exceed 1-3000th of an inch. In using these fibres for measuring the angle subtended by two luminous points, the fibres may be separated, as hitherto done, till the luminous points are in contact with the inferior surfaces; but, in order to avoid the error arising from inflection, it is proposed to separate the fibres, till the rays of light issuing from the luminous points dart through the transparent axis of the fibres. The rays thus transmitted, evidently suffer no inflection in passing through the fibre to the eye; and, besides this advantage, the observer has the benefit of a delicate line, about one-third of the diameter of the fibre itself.*

The principle of the new micrometer invented by Dr. Brewster, is to have one or more pieces of wires absolutely fixed in the field of the telescope, and to separate them by an optical instead of a mechanical contrivance; for it is obviously the same thing, whether the wires are opened to embrace the sun's diameter, or the sun's diameter magnified till it fills the space between the wires. This change, however, in the magnitude of the object, must be effected in a part of the telescope anterior to the wires. In order to accomplish this, a second object-glass is made to move between the principal object-glass and its focus, by which means the magnifying power of the instrument, and consequently the angle subtended by the wires, may be constantly changed. When the object-glasses are in contact, the angle subtended by the wires is a maximum; and when they are at their greatest distance, the angle is a minimum, and every intermediate angle between these two is measured by a scale of equal parts, equal to the focal length of the principal object-glass. In this construction, the imperfections of the screw, the error arising from the uncertainty of the zero, from the bad centering of the lenses, from the want of parallelism in the wires, and from the minuteness of the scale, are completely removed.

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* It may be proper to state, that Professor Wallace, of the Royal Military College, has suggested the employment of asbestos fibres in lieu of the fine wire or spider's web previously used for the *eye-piece micrometer*, and a filament about 1-3000th of an inch in diameter, having been applied to a telescope, was found to answer very perfectly the purpose for which it was intended.

The inventive genius of Dr. Wollaston has, however, far outstripped those who preceded him in the production of a micrometer fibre. The contrivance by which it is effected, is so ingenious, and promises to be productive of such valuable results, that it may be advisable to annex the account of the process employed by this philosopher.

"The extremity of a platinum wire having been fused into a globule nearly one-fourth of an inch in diameter, was next hammered out into a square rod, and then drawn again into a wire 1-253rd of an inch in diameter. One inch of this wire duly coated with silver, was drawn till its length was extended to one hundred and eighty two inches; consequently, the proportional diminution of the diameter of the platina will be expressed by the square root of 182, so that its measure had become $\frac{1}{253 \times 13{,}5} = \frac{1}{3415}$. The specific gravity of the coated wire was assumed to be 10.5, and since the weight of one hundred inches was one hundred and fourteen grains, its diameter was inferred to be 1-42,8th of an inch, or just eighty times that of the platina contained in it."

The principle of the preceding micrometer applies most happily to the Gregorian and the Cassegrainian reflecting telescopes; and, what at first sight may appear paradoxical, these instruments may be converted into a very accurate micrometer, almost without the aid of any additional apparatus. A moveable object-glass is not necessary, as in the former case; for the magnifying power of these reflecting telescopes may be varied, merely by varying the distance between the eye-piece and the great speculum.

The same optical principle constitutes the foundation of the new divided object-glass micrometer. In the old micrometer of this construction, invented by Savery, two semi-lenses were made to separate from and approach to each other by a fine screw; and when the two images of the object were in contact, the distance of the centres of the semi-lenses was a measure of the angle which it subtended. In Dr. Brewster's micrometer, however, the semi-lenses, fixed at an invariable distance, are made to move between the object-glass and its focus, so that the two images can easily be brought into contact, and the angle measured upon a scale of equal parts as large as the focal length of the object-glass.

SIMPLE ELECTRICAL PHENOMENA.

Excitation of Bodies.—Attraction and Repulsion.—Power of Conduction.—Construction of the Electrical Machine.—Improved Cylinder and Plate Machines.—Leyden Experiment.—Coated Electrics.—Battery.—Electrometers.

The common phenomena of *electricity*[*] were well known to the ancients, though they do not appear to have been aware of the connexion that subsists between atmospheric electricity, or lightning, and that which is produced by artificial means. Electrical phenomena are usually characterised by the attraction and recession of light substances; the consequent production of motion in them, and of sensation in living bodies, and by the evolution or production of light. There are various methods by which these effects may be produced, but the following are the most obvious sources of their production. Friction; change of form; change of temperature; contact of dissimilar bodies.

Of the first kind, viz. friction, the instances are most numerous, and, under certain limitations, universal; they may indeed be obtained by rubbing any of an extensive list of resinous and siliceous substances: and of dry, vegetable, animal, and mineral productions. The electricity thus excited, is most readily rendered visible by its effects on the gold leaf electrometer.

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[*] This science appears to have derived its name from that of the first substance in which any of its properties were discovered. This was amber, the Greek name of which is ηλεκτρον, evidently derived from 'Ηλεκτωρ, a name by which Homer designates the sun. It has been said by some that the ancients, observing amber to possess the property of attracting light substances when rubbed, termed it electrum, and that hence arose the word electricity. Those who entertain this opinion, would derive the name from the Greek verb ελκω, to draw; though this appears to be a very forced derivation, as amber was called by the name of electron long before it was known to possess the magnetic property of attraction.

Examples of the second kind are also very numerous. If a small quantity of sulphur be melted and poured into a conical wine glass, it will contract slightly, and become electrical in cooling. A silk thread with a small hook at the end of it, or a rod of glass should be inserted in the sulphur while in a fluid state, to serve as a handle for separating it from the glass when cold. On being separated from the glass, the sulphur will exhibit other signs of electricity; if kept in the glass, it will retain its electric virtue for years, and evince it very perceptibly on every attempt to separate the two substances.

Mr. Henly discovered that chocolate, fresh from the mill, becomes strongly electrical, as it cools in the tin pans. It soon loses this property, but recovers it once or twice, by being melted in an iron ladle and poured into the tin pans. When the mass becomes dry, the electricity cannot be restored by melting, unless olive oil be mixed with it in the ladle; in which case it completely recovers its electric power. M. Chaptal observed the same circumstance during the congelation of glacial phosphoric acid. The condensation of vapour, and the evaporation of fluids, though apparently opposite processes, are alike sources of electrical excitation.

Various crystallized gems, and a stone called the tourmalin, become electrical by the mere application of heat; and the effects of friction are generally increased, if it is preceded by a moderate elevation of temperature.

The contact of dissimilar bodies is probably in all cases the real primary cause of electrical excitement; but it is rarely employed alone, for electricity is known to us only by its effects, which are constantly the result of an artificial arrangement, and consequently may not immediately succeed the primary cause of electric powers, similar in their separate action on the electrometer, and other indifferent matter; but exerting a mutual influence on each other, destructive of their individual properties.

It was at first supposed that these phenomena were peculiar to the substances by which they were produced; hence the power excited by the friction of glass was termed vitreous electricity; and that by the friction of sealing-wax, resinous electricity. It has, however, long since been proved that both powers are produced in every case of electrical excitation; and, because their mutual counteraction of effect resembles that of an affirmative and negative power, they have been styled *positive* and *negative* electricity.

The determination of these two states of electricity in different excited bodies is of importance to the practical electrician, and may be thus effected:—Sealing-wax when rubbed on woollen cloth is negatively electrified. Glass, when rubbed with silk is positively electrified. Let an electrometer be made to diverge by its being approached by an excited stick of sealing-wax: while in this state, approach it with any excited body, the electricity of which is to be determined. If the divergence of the electrometer increase, the presented body is negative; if it be diminished, the presented body is positive. In other words, all those substances that lessen the divergence occasioned by excited wax, are positive; and such as increase it, negative: whilst those which lessen the divergence produced by excited glass, are negative; and such as increase it, positive.

As an illustration of the doctrine here advanced, let the following simple and easily performed experiments be made. Roll up a warm and dry piece of flannel, so that it may be held by one extremity, while a stick of sealing-wax is rubbed with the other. After a slight friction, present the flannel to an electrometer, which will instantly diverge; while this divergence continues, bring the stick of sealing-wax near the cap, and the leaves of the electrometer will quickly collapse. Both these substances, it is obvious, are electrified by mutual friction, but their electricities are opposite; that of the wax being negative, and that of the flannel positive.

The electricities thus produced are equal to each other: for if the friction be repeated, and the two substances be both presented to the electrometer at the same time, no signs of electricity appear: the opposite electricities, when applied together, producing a reciprocal counteraction of effect.

If a black and a white silk riband be excited in contact, in the manner already described, the black riband will be found to be negatively and the white one positively electrified.

Take the sulphur cone already described, apply it and the glass separately to the electrometer; the cone will be found to be negatively, and the glass positively electrified.

From the above experiments it appears, that in all cases of excitation, positive and negative electricity are produced at the same time, and may be observed by the use of proper means. But it also appears that by friction with the same substance, different bodies are variously affected; for glass rubbed with silk evinces positive electricity: but wax rubbed with silk is rendered negative. Again, polished glass, when rubbed with silk, skin-wool, or metal, becomes positive; but if it be excited by friction against the back of a living cat, it appears negative. Wool, silk, or fur, rubbed against sealing-wax, are rendered positive; but gold, silver, or tin, are by the same process rendered negative.

Electricians have drawn up tables for showing at one view what kind of electricity will be produced by rubbing various electrics with different substances; the following may be adduced on the authority of Mr. Cavallo.

	Is rendered	By friction with
Smooth Glass	Positive	Every substance hitherto tried, except the back of a cat.
Rough Glass	Positive	Dry oiled silk, sulphur, metals.
	Negative	Woollen cloth, quills, wood, paper, sealing-wax, white wax, the human hand.
Tourmalin	Positive	Amber, blast of air from bellows.
	Negative	Diamonds, the human hand.
Hare's skin	Positive	Metals, silk, loadstone, leather, hand, paper, baked wood.
	Negative	Other finer furs.
White Silk	Positive	Black silk, metals, black cloth.
	Negative	Paper, hand, hair, weasel's skin.
Black silk	Positive	Sealing wax.
	Negative	Hare's, weasel's, and ferret's skin, loadstone, brass, silver, iron, hand, white silk.
Sealing wax	Positive	Some metals.
	Negative	Hare's, weasel's, and ferret's skin, hand, leather, woollen cloth, paper, some metals.
Baked Wood	Positive	Silk.
	Negative	Flannel.

The effects of attraction and repulsion which result from the friction of these bodies, may be rendered apparent by a variety of contrivances. It may be advisable to select a few of the most simple.

If we take a small downy feather or a pith ball suspended by a thread, and, holding the thread, bring the ball near an electrified conductor, either positive or negative:

the ball will be attracted by the electrified conductor, and adhere to it, until its electricity is destroyed.

Such bodies as are positively electrified, tend to diffuse their superabundant fluid amongst surrounding substances; and those that are negative, endeavour to acquire the electric fluid: hence, either state of electricity will produce attraction; for if light bodies are to be moved, it is indifferent whether the electrified surface attracts their natural electric fluid, or the matter to which it is attached; for the attraction arises only from the different proportions of these in any two bodies, and will of course continue whilst that difference exists.

We may repeat the preceding experiment with a ball or feather supported by a silk thread: the light body will first be attracted to the electrified conductor, and will then recede from it; nor can it again be brought in contact until it has touched some conducting substance. The light body is here attracted for the same reason as before, but it is insulated, and consequently receives, by contact with the electrified surface, a similar electric state; it therefore recedes from that surface, being attracted by the ambient air, or other surrounding bodies; for they have their natural portion of electricity, and therefore differ from the light body, which has either more or less; but the electrified surface does not differ from the light body, and consequently cannot attract it, till, by touching some conductor, its natural electric state is restored.

We may add a very pleasing variety of the last-mentioned experiment.—Take a glass tube, whether smooth or rough is not material, and, after having rubbed it, let a small light feather be let out of your fingers at the distance of about eight or nine inches from it. This feather will be immediately attracted by the tube, and will adhere very close to its surface for about two or three seconds, and sometimes longer; after which it will be repelled; and, if the tube be kept under it, the feather will continue floating in the air at a considerable distance from the tube, without coming near it again, except it first touch some conducting substance: and, if the tube be managed dexterously, the operator may drive the feather through the room at pleasure. This experiment may be varied as follows: a person may hold in his hand an excited tube of smooth glass, and another may hold an excited rough glass tube, a stick of sealing-wax, or any other electric negatively electrified, at about one foot and a half distance from the smooth glass tube; a feather now may be let go between these two differently excited electrics, and it will leap alternately from one electric to the other.

Some bodies possess the power of accumulating, others of transmitting this subtle fluid, and experiment shows that there is a gradation of effect from one class of bodies to the other. Those which transmit electricity with facility are called conductors; those whose transmitting powers are inferior, imperfect conductors: and such as have no power of transmission, non-conductors; but in general the various bodies in nature are divided into two classes only; the remote extremes of each forming the intermediate class.

In the following enumeration of the principal conductors, the substances are placed nearly in the order of their perfection; but the determination of this circumstance has not hitherto been accomplished with much precision.

All the known metals.
Well-burnt charcoal.
Plumbago.

Concentrated acids.
Powdered charcoal.
Diluted acids, and saline fluids.

Metallic ores.
Animal fluids.
Sea water.
Spring water.
River water.
Ice above 13° of Farenheit.
Snow.
Living vegetables.
Living animals.
Flame.
Smoke.
Steam.
Most saline substances.
Rarefied air.
Vapour of alcohol.
Vapour of ether.
Most of the earths.
Most stones.

To the above, Dr. Brewster adds powdered glass and powdered sulphur, which, he says, have been found to be conductors by the experiments of Van Swinden.

Many of the above-mentioned substances fail to conduct electricity when they are made perfectly dry; hence it is concluded that their conducting power arises from the water they contain. Indeed, this faculty does not permanently exist in any of the bodies enumerated, but varies and disappears with their modifications of temperature, &c. Thus hot water is a much better conductor than cold water is; the same is the case with charcoal and other substances.

The *non-conductors* are also called electrics; they are as follows:

Shell-lac, amber, resins.
Sulphur, wax, jet.
Glass, and all vitrifications, talc.
The diamond, and all transparent gems.
Raw silk, bleached silk, dyed silk.
Wool, hair, feathers.
Dry paper, parchment, and leather.
Air, and all dry gases.
Baked wood, dry vegetable substances.
Porcelain, dry marble.
Some silicious and argillaceous stones.
Camphor, elastic gum, lycopodium.
Native carbonate of barytes.
Dry chalk, lime, phosphorus.
Ice at 13° of Fahrenheit.
Many transparent crystals when perfectly dry.
Ashes of animal bodies.
Ashes of vegetable bodies.
Oils, the heaviest are the best.
Dry metallic oxides.

Many substances in the preceding list lose their non-conducting power, and become conductors, when intensely heated. Such is the case with red-hot glass, melted resin, wax, &c.; but the most intensely heated air, if unaccompanied by flame, is not a conductor. Many fibrous substances attract water so readily, that it is absolutely necessary to dry and warm them before their non-conducting property appears; this is particularly the case with paper, flannel, parchment, leather, &c. The influence of heat on this property is, indeed, very remarkable. It is well exemplified in the following instance: wood, in its natural state, is a conductor; if baked, its moisture is expelled, but its organisation is not altered: it is then a non-conductor. By exposure to a greater heat, its volatile elements are dissipated, and its indestructible base (charcoal replete with alkali) only remains; this is a conductor; but if exposed again to heat, with access of air, it suffers combustion, and is converted into ashes and gases, which are non-conductors.

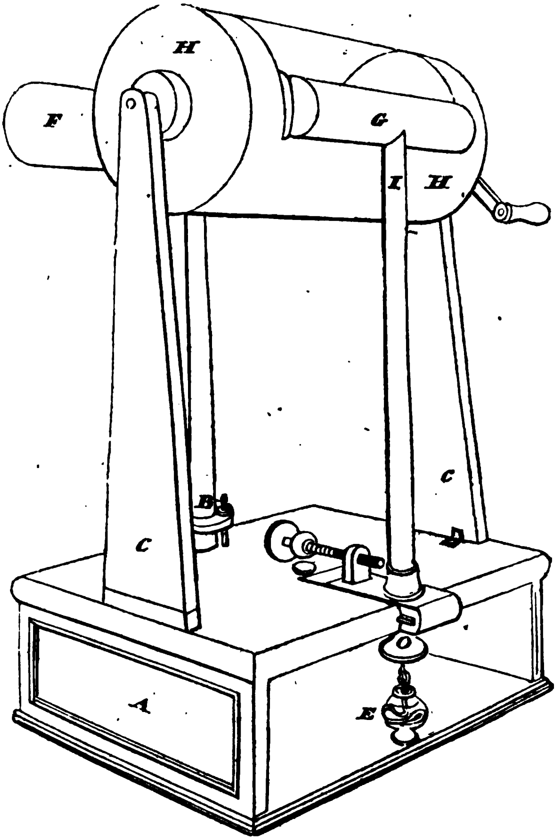
When electricity is excited by friction, the quantity of effect is, within certain limits, proportioned to the extent of the rubbed surface; hence it appears that every part of that surface is concerned in the production of the general effect. Now, that this may be the case, it is essential that every part of such surface be insulating; for friction is a progressive process, a succession of contacts; and the effect produced by it in the first instant would otherwise be destroyed by conducting power, before a second operation could contribute to its increase. For this reason electricity is most usually excited by the friction of a conductor of limited size, against the extensive surface of a non-conductor.

An apparatus, then, properly arranged for the excitation of electricity, is called an *electrical machine*. We have seen that, to excite positive electricity, a glass tube may conveniently be used; the excitation is produced by rubbing it lengthwise by a piece of dry oiled silk, held in the hand, which is made to grasp the tube. In this way both the silk and the tube are electrified; but the electricity of the silk is destroyed by the conducting power of the hand, and that of the tube only appears. In a similar way negative electricity is procured by rubbing a large stick of sealing-wax with dry flannel or fur; the electrical power of the sealing-wax being all that results.

Thus, with the most simple machinery, two processes are employed to procure the opposite electricities, although they are at the same time both excited in each; but, to obtain them both, it would be necessary to insulate the silk, or flannel, used as rubbers, either by employing them in a very dry state, rolled up, so as to produce the friction with one extremity, at a distance from the hand, or by affixing them to a glass or other non-conducting support; but neither of these methods would be convenient where many experiments are to be made. This difficulty does not occur when large surfaces of glass are employed instead of tubes as sources of excitation; for these may be made circular, and proper friction be communicated to them from a fixed cushion, placed on an elastic support, against which they are made to revolve.

In examining the construction of the *cylinder electrical machine*, it may be advisable to select that form which combines portability with a high exciting power. A cylinder machine of this description, contrived by Mr. Ronalds, is represented in the accompanying figure, which possesses these advantages in a very eminent degree.

The cylinder H is excited by revolving on its axis, in



contact with the rubber or cushion, G. The prime-conductor F, forms a magazine for holding the electricity which has been separated from the rubber; and for which purpose it is provided with a series of metallic points, which readily draw electricity from the cylinder. A dovetail joint and screw are placed at the bottom of the rubber, to ensure the right degree of pressure on the glass. A, is a box, or case, forming the base of the machine; I, is a copper pipe, the support of a half-cylinder G, also of copper, and hollow, into which the support I opens, and which carries the cushion and rubber; E, is a very small spirit lamp, the burner of which is formed by only one thread of cotton, and it is placed immediately beneath the mouth of the copper pipe, I.

The prime-conductor must be placed on a nearly similar tube formed of glass. A cylinder machine, thus constructed, of half the dimensions of one made upon the usual plan, is very powerful in its operation, and, what is better, always effective. It is most convenient for medical purposes; and if it be required to add the advantage of portability, let the box, or case, A, be enlarged sufficiently to contain a drawer, which may receive the dismounted cylinder, the rubber with its support, and all other necessary apparatus. The two supports, *c c*, of the cylinder, being provided with hinges, may be shut down upon the top of the box, and thus the whole reduced to convenient dimensions for any mode of conveyance.

The most powerful excitation of the machine is produced as follows:—Let the machine be placed within the influence of a good fire, but not so near as to injure any of its parts by the action of the heat. With a flat round pointed knife spread a little amalgam evenly along the cushion, and return it to its place: turn the cylinder a few times round; then take off the cushion, and observe carefully those parts on its surface that have not been touched by the cylinder while revolving; on these parts put a little more amalgam, and repeat the process of turning the cylinder, and supplying the defective parts with amalgam, till every point of that part of the surface of the cushion which presses on the cylinder appears to be properly supplied with amalgam.* Take now a piece of leather about five or six inches square, and spread over one side of it a quantity of amalgam; throw back the silk flap, and, turning the machine gently round, apply the amalgam side of the leather to the cylinder for the space of a few minutes, during which time the excitation will be observed to increase rapidly. The cylinder must next be wiped perfectly clean with an old silk handkerchief, and afterwards with a soft dry linen cloth. Let the cushion be again removed, and the amalgam which appears above and below the line of contact with the cylinder carefully scraped off, the silk flap wiped with a linen cloth, and the whole returned to its place and made fast. If now the cylinder be turned slowly round, streams of the electric fluid will be seen rushing from the silk flap round the lower part of the cylinder, attended with a hissing and snapping noise, while large brushes of the same, of several inches in length, may be observed flying off from the lower edge of the silk into the surrounding air. The machine is now fit for use, and may be fastened to the table; after which the whole of its parts are to be well wiped with a warm and dry linen cloth to free them from dust.

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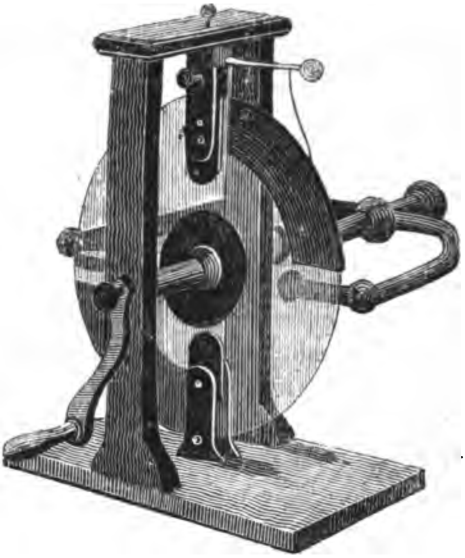
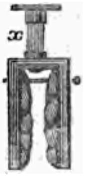
* The following directions for preparing the amalgam for electrical machines are given by Mr. Singer. Melt in an iron ladle two ounces of zinc with one ounce of tin, and, while this mixture is in a fluid state, pour into it six ounces of mercury; let the whole be then put into an iron or wooden box, and agitated until it be quite cold. It must then be reduced to fine powder in a mortar, and mixed with sweet hogs' lard to the consistence of thick paste. This part of the process need not be performed till the amalgam is wanted for use. This amalgam, he remarks, answers exceedingly well; but, he afterwards adds, I have since made it with a still less proportion of mercury with equal effect. The proportions may be two ounces of tin, four ounces of zinc, and seven ounces of mercury. The mercury must be heated to about 300° of Fahrenheit, before the fused metals are added to it. When the amalgam has been agitated until cool, and finely powdered, it is to be mixed with hogs' lard by trituration in a mortar: and should it at any time become hard, more lard must be added, and the trituration be repeated.



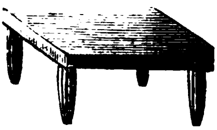
A *plate electrical machine* is represented in the above diagram. It consists of a circular plate of glass, turning on an axis that passes through its centre: it is rubbed by two pairs of cushions fixed at opposite points of its periphery by elastic frames of thin mahogany, which are made to press the glass plate between them with any required degree of force, by means of regulating screws. A brass conductor, supported by glass, is fixed to the frame of the machine, with its branched extremities opposite each other, and near the extreme diameter of the plate, in a direction at right angles to the vertical line of the opposite cushions. The branched extremities of the conductor are furnished with pointed wires, that serve to collect the electricity from the surface of the excited plate.

If we wish to procure negative electricity from this machine, the rubbers may be insulated by attaching the frame to a glass tube *x*; but the usual mode of effecting this object is to place the whole apparatus on a glass-legged stool, and employ a glass handle to give motion to the cylinder.



The largest specimen of this instrument is that which was constructed by Mr. Cuthbertson, for Tyler's museum, at Haarlem. The following brief description will furnish some notion of the powers of this immense machine; and its construction will be readily understood by the description which we shall add of the most improved form of the instrument. It consists of two circular plates of glass, each sixty-five inches in diameter, and made to turn upon the same horizontal axis, at the distance of seven inches and a half from one another. These plates are excited by eight rubbers, each fifteen inches and a half long. Both sides of the plates are covered with a resinous substance to the distance of sixteen inches and a half from the centre, both to render the plates stronger, and likewise to prevent any of the electricity from being carried off by the axis. The prime conductor consists of several pieces, and is supported by three glass pillars fifty-seven inches in length. The conductor is divided into branches, which enter between the plates, but collect the fluid by points only from one side of the plate. The force of two men is required to work this machine; but when it is required to be put in action for any length of time, four are necessary. At its first construction nine batteries were applied to it, each having fifteen jars, every one of which contained about a foot square of coated glass; so that the grand battery, formed by the combination of all these, contained one hundred and thirty-five feet.

It is sometimes advisable, for medical and other purposes, to make a sort of living prime conductor, and, as such, to draw sparks from the body. This is effected by the use of a glass-legged stool. With an apparatus of this kind, the medical electrician is enabled to insulate his patient, and apply this powerful agent in the most advantageous way.



In the formation of the prime conductor, as well as in every other part of the machine that is intended to retain electricity, sharp angular points, or other asperities, should be particularly avoided.

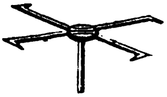
The action of bodies that are pointed or angular appears to consist in promoting the recession of the particles of electrified air, by protruding a part of the electrical atmosphere of the conductor into a situation more exposed to the action of the ambient unelectrified medium, and thereby producing a current of air from the electrified point to the nearest uninsulating body. On this account, the most prominent and the most pointed bodies are such as transmit electricity with the greatest facility; for with them this condition is most perfectly obtained.

A spherical surface is that which, considered with regard to its surrounding atmosphere, is most uniform; hence balls, or cylinders, with rounded ends, are naturally employed for insulated conductors, and their magnitude is proportioned to the intensity of the electrical state they are intended to retain; for a point is but a ball of indefinite diameter, and will act as such on very small quantities of electricity; and a ball of moderate size may also be made to act as a point, by electrifying it strongly.

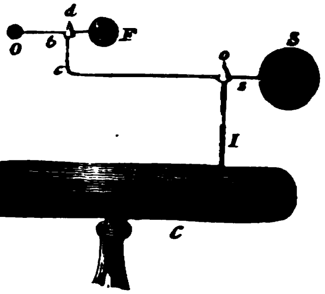
If two spheres of equal size are connected together by a long wire and electrified, their atmospheres will extend to the same distance, and they will of course have respectively the same intensity; but if the spheres be of unequal size, the atmosphere of the smallest will extend farthest, and it will necessarily have the greatest intensity; so that a longer spark can be drawn from a small ball annexed to the side of a conductor, than from the conductor itself, and longer in proportion as the ball projects farther from the side. Hence, the finer the point, and the more freely it projects beyond any part of the conductor to which it is annexed, the more rapidly will it receive or transmit electricity.

The facility with which pointed bodies transmit electricity has given rise to several very delicate and beautiful experiments to illustrate their operation: of these, the following are the most deserving of attention.

The *electrical fly* may first be noticed. It is shown beneath, and is composed of four small brass wires, fixed into a cap of the same material, easily movable upon a metal axis, and exactly balanced, so that they may turn with the smallest possible force. The ends, which ought to be very sharp, should all be bent in one direction. With an apparatus of this kind, and a powerful machine, several flies may be made to turn either in the same, or in contrary directions; and, by their gradual increase or decrease in size, may represent a cone or other figure; for the course of each will be marked by a line of fire, and thus the whole will exhibit a beautiful appearance in the dark. The flies, in this experiment, turn the same way, whether the electricity be positive or negative.



The *electrical orrery* is another instrument frequently used for showing the effects of points in the transmission of the electric fluid. Its construction is shown in the accompanying diagram; the ball S represents the sun, F



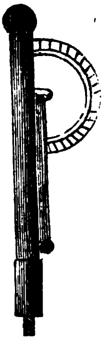
the earth, and *o* the moon, connected by wires *s c*, and *b*; *d*, is the centre of gravity between the earth and moon. These three balls and their connecting wires are supported by the sharp point of a wire, I, which is placed upright in the prime conductor of the electrical machine; the earth and moon hanging upon the sharp point of the wire *c*, in which wire is placed a short pin, projecting horizontally at *c*; and there is a similar pin at *o*, projecting in the same manner from the wire that connects the earth and the moon.

When the cylinder of the electrical machine is turned, these balls and wires are electrified; and the electrified air, flying off horizontally from the points, drives the balls round their common centre of gravity.

The *electrometer*, or *electroscope*, is a very valuable part of the electrical apparatus. By the use of this instrument, which has been variously modified and improved by Bennet, Singer, and Coulomb, we are enabled to ascertain the presence of electricity in cases where the quantity would be otherwise too small for observation.

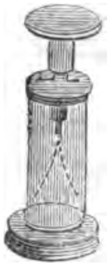
The most simple apparatus for ascertaining the amount of electrical repulsion, consists of two pith balls attached to threads, and connected with the prime conductor of the machine, so that their divergence serves as a measure of the electrical intensity.

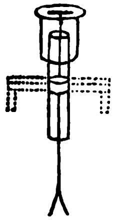
Another form of the pith-ball electrometer is that invented by Mr. Henley; it is simple in its construction, and extremely useful in numerous electrical experiments It consists of a perpendicular stem formedat top like a ball, and furnished at its lower end with a brass ferule and pin, by which it may be fixed in one of the holes of the conductor, or at the top of a Leyden jar. To the upper part of the stem, a graduated ivory semicircle is fixed about the middle of which is a brass arm or cock, to support the axis of the index. The index consists of a very slender rod, which reaches from the centre of the graduated arch to the brass ferule; and to its lower extremity is fastened a small pith ball nicely turned in a lathe. When this electrometer is in a perpendicular position, and not electrified, the index hangs parallel to the pillar; but when it is electrified, the index recedes more or less, according to the quantity of electricity, from the stem. The scale in Mr. Henley's quadrant is divided into equal parts; but M. Achard has shown that, when this is the case, the angle at which the index is held suspended by the electrical repulsion is not a true measure of the repulsive force: to estimate this force truly, he demonstrates that the arc of the electrometer should be divided according to a scale of arcs, the tangents of which are in arithmetical progression.



The *gold-leaf electrometer* is a very valuable and delicate piece of apparatus. It consists of two thin leaves of metal suspended by a cap in a glass insulating cylinder. These, when electrified, immediately repel each other, and show by their divergence the amount of repulsion.

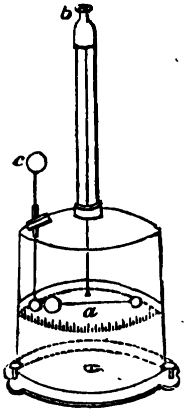
There have been some improvements proposed on this electrometer, one of which was by Mr. Singer, and chiefly respects the mode of insulation. This instrument is represented in the accompanying figures, in which a section and



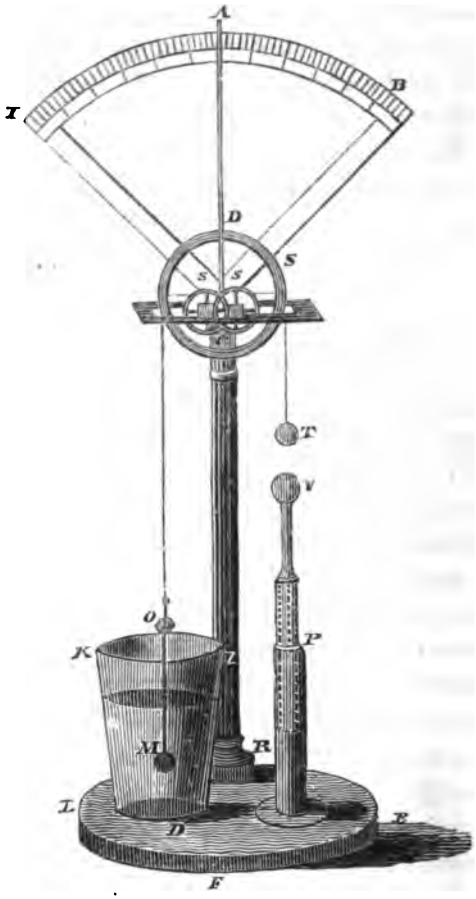


complete view of the exterior of the instrument is furnished. The following brief description will suffice to convey a correct idea of it. Like the preceding, it is constructed with a glass cylinder, surmounted by a broad cap of either wood or metal. The insulation depends on a glass tube of four inches long, and one-fourth of an inch in diameter, covered on both sides with sealing-wax, and having a brass wire of a sixteenth or twelfth of an inch thick, and five inches long, passing through its axis, so as to be perfectly free from contact with any part of the tube, in the middle of which it is fixed by a plug of silk, which keeps it in a concentric position with the internal diameter of the tube. A brass cap is screwed upon the upper part of this wire; it serves to limit the atmosphere from free contact with the outside of the tube, and at the same time to defend its inside from dust. To the lower part of the wire the gold leaves are fastened. The glass tube passes through the centre of the cap of the electrometer, and is cemented there about the middle of its length. When this construction is considered, it will be evident that the insulation of the wire, and also of the gold leaves, will be preserved until the inside as well as the outside of the glass tube becomes coated with moisture; but so effectually does the arrangement preclude this, that some of these electrometers have remained for years without being either warmed or wiped, and have still appeared to retain the same insulating power as at first.

The electrometers already described have all been found highly useful to the practical electrician, according to the peculiar nature of the course of his experiments; but for ascertaining the actual repulsive and attractive powers of very faintly electrified bodies, they are perhaps all excelled by the ingenious invention of M. Coulomb, a French philosopher. The construction of this delicate instrument, which is called the *torsion balance*, will be best understood by a reference to a figure. The apparatus consists of a hollow glass cylinder, graduated so as to indicate degrees and parts of a degree. On this is placed a flat plate of glass, furnished with a tube in the centre, supporting a nut *b*. A silk string descends through the tube, to which is attached the index hand, *a*. The ball and wire *c* is insulated on the glass plate, and serves to communicate electricity from external objects, and the amount is indicated by the twisting of the string.

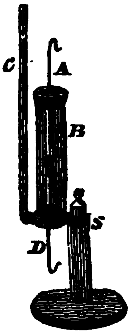


The action of *Harris's electrometer* depends on balancing the attractive force of accumulated electricity, by the increased weight which a body immersed in a fluid gains on rising out of it. It consists of a stand R, E, L, F; on

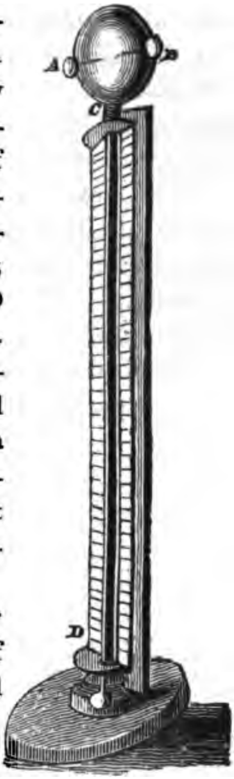


this is screwed the perpendicular column R ; it supports a projecting plate of brass, S, and a large wheel, D; the axle of this wheel rests on four small friction wheels S, S, and its centre is that of the arc B I ; this arc is a quadrant, divided into any number of equal parts on each side of its centre, marked Zero ; the large wheel D, carries an index, formed of a fine strong straw, to indicate the attractive forces in the direction A, B, and the repulsive in the direction A, I; over the wheel passes a line S, to which is suspended a light ball of gilt wood T. The float, sustained, in great part, by the fluid in the vessel K, preserves an equilibrium when the index is at zero. The line passing over the pulley, if the attractive forces are to be estimated, is formed of two parts, the lower part being of silver thread, the remainder silk. When the repulsive forces are to be estimated, the whole is of silk. The float O M, is a small glass tube, about two-tenths of an inch diameter, terminating in a small bulb at its lower end, which contains some very fine shot, or mercury, occasionally put into it for the purpose of adjusting the instrument. The fluid is distilled water of a mean temperature. The difference of weight of this float, when in and out of the water, is known; and every tenth of an inch of it, which rises out or sinks into the fluid, is made to correspond, by employing a wheel of the required circumference, with five divisions of the arc above: we can hence readily estimate the force of the attraction in grains, and parts of a grain. Under the ball T, is placed a larger insulated ball V, in connexion with the prime conductor, or inner coating of the jar; it can be depressed or elevated by means of the sliding tube P, through divisions of one-tenth of an inch, which correspond, also, to every five divisions on this arc; and this enables us to obtain any multiple of the first force, and yet preserve the ultimate distance between the balls constant. Now it is evident, that the attractive or repulsive forces, operating in right lines between the balls, will cause the float to ascend or descend, until the weight gained or lost by its rising or sinking in the fluid furnishes a balance to the forces. The column is of baked wood, and has a wire through it, which, when the attractive force is alone measured, is connected at the base with the outside of the jar, or battery, and hence the interval between the inner and outer coating is that between the balls T and V; so that, when charging, the attraction between the balls will increase with the accumulation; hence the index moving over the arc I, B, is a true measure of it.

The *electrical air thermometer* was originally contrived by Mr. Kinnersley, of Philadelphia, and described by that gentleman in a letter to Dr. Franklin, early in 1761. The annexed diagram will represent the ordinary mode of constructing this instrument. A wire A is made to enter the glass tube B, by a metal cap, through which it passes, air-tight; a similar wire D passing up from the lower end. A glass tube C, forms the only communication with the atmosphere; so that if a small portion of any coloured fluid be placed in the large vessel, and the air above it be expanded, the coloured fluid must be driven up the tube. This is most readily effected by connecting the two coatings of a charged jar with the wires A and D.



The experiments which Mr. Kinnersley made with this instrument are as follows:—He placed the thermometer on a stand S, and connected the wire A with the prime conductor of an electrical machine in action. He, by this means, kept the air electrified for a considerable time, without producing any peculiar effects; from whence he inferred, that the electrical fluid, when in a state of rest, had no more heat than the air in which it might reside. When the two wires were in contact also, and a powerful shock passed through the apparatus, little or no effect was produced: but when the wires were placed about two inches asunder, the charge of a small jar rarefied the air very considerably. The charge of a jar containing about five gallons produced a prodigious rarefaction in the air, frequently raising the fluid to the top of the tube.



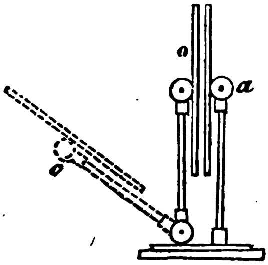
Another air-thermometer may be noticed. Its construction was suggested by Lieut. Harris, and it consists merely of a glass bulb furnished with a capillary tube, containing a small portion of any coloured fluid. The stem, D, is inserted in a mahogany stand, which preserves it in a perpendicular position; and a graduated index, passing from D to C, indicates the height of the fluid. Two rings at A and D, form the communication between the internal and external coatings; so that, on making a communication between them, a portion of air is displaced, and the amount is found to differ very materially in different gaseous bodies.

Condensers are instruments used for the detection of very small portions of electricity, too minute to be rendered sensible by the electrometer.

Volta appears to have been the first electrician who constructed an apparatus of this description. His condenser of electricity consisted of a flat and smooth metal plate, furnished with an insulating handle, and a semi-conducting, or imperfectly insulating plane. The principle on which the action of this apparatus depends, says Mr. Cavallo, " is, that the metal plate, whilst standing contiguous to the semi-conducting plane, will both absorb and retain a much greater quantity of electricity than it can either absorb or retain when separate; its capacity being increased in the former, and diminished in the latter case."

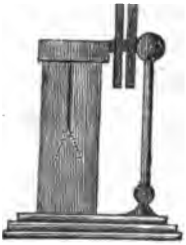
This condenser was afterwards improved by Mr. Cavallo, who employed a small metallic plate, about the size of a shilling, having affixed to it a glass handle covered with sealing-wax. When the larger plate appeared so slightly electrified by the communicated electricity as not to affect the electrometer, he then placed the small plate on the plane, and touched it with the edge of the large one, holding the latter in an almost vertical position; the small plate was thus found to indicate a very sensible degree of electricity.

One of the most convenient and elegant condensers yet contrived is that of Mr. Cuthbertson. This instrument is shown in the engraving, and is composed of two metallic



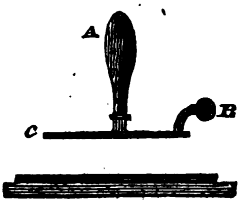
plates, *a* and *c*, about six inches in diameter, tightly screwed to two brass balls, but so as that one of them be fixed immovably to a glass pillar, as *a*, while the other is fastened to a brass pillar, having a hinge at its lower extremity, by which it can be moved backwards from the position *o*. When the instrument is used, the electricity to be examined is communicated to the insulated plate *c*, while it is parallel to the uninsulated plate *a*; and after remaining for some time in this position, the uninsulated plate is drawn back, and the intensity of the insulated plate *c* is shown by being presented to an electrometer in the usual way.

A modification of this instrument, called the condensing electrometer, is represented in the accompanying figure. In this construction the plates are smaller, and the insulated plate is attached to the cap of a gold-leaf electrometer; by this means very small degrees of electricity are discovered, and their intensity shown by the divergence of the gold leaves within the cylinder.



A condenser of a remarkably simple description was proposed by Mr. Singer, and is constructed by placing three small spots of sealing-wax, at equal distances, on the lower face of the cover of an electrophorus, to serve as insulating feet, by which the cover may be supported at the distance of about the twelfth of an inch from the surface of a smooth and even table. If a Leyden jar, he adds, be now charged, and afterwards discharged, so as not to affect an electrometer, and its knob be then placed in contact with the condenser resting on the table for a few seconds, the small residuum of electricity in the jar will be absorbed by the condensing plate; and when this is raised from the table, it will affect the electrometer with the same electricity as that with which the jar was charged.

The *electrophorus* is sometimes employed as a substitute for the electrical machine. The accompanying figure furnishes a view of this useful piece of apparatus, which is easily constructed by a reference to the following directions. Procure two circular plates of metal, or of



wood covered with tin-foil, and well rounded at the edges; these are the conductors: between them is placed a resinous plate, formed by melting together equal parts of shell-lac, resin, and Venice turpentine, and pouring this mixture, whilst fluid, into a tin hoop of the required size, placed on a marble table, from which the plate may be readily separated when cold. This plate should be half an inch in thickness; it is sometimes made by pouring the mixture on one of the conductors, which is then formed with a rim for that purpose. In the centre of the upper conductor is fixed a glass handle A, for the purpose of lifting it without drawing off its electricity; and, when the electric state of the lower conductor is to be examined, the whole apparatus must be placed on an insulating stand. To use the electrophorus, rub the upper surface of the resinous plate with a piece of dry fur; cat's skin is reckoned the best, and it will be excited negatively. Place the upper conductor *c* upon it, and then raise the same by its insulating handle; it will be found to exhibit very faint, if any, electrical signs Replace the conductor, and, whilst it lies on the surface of the excited plate, touch it with a finger or any other uninsulated conductor, and then raise it again by its handle. It will now be positively electrified, and afford a spark at B: if it be then placed on the resinous plate, touched, and again raised, another spark will be procured; and this process may be repeated for a considerable time without any perceptible diminution of effect.*

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* The facility with which inflammable air is lighted by even a moderate electric spark, suggested to Volta the construction of an inflammable air-lamp (for a modification of which a patent was some time since procured as a source of instantaneous light). It consists of a reservoir filled with hydrogen gas, subject to the constant pressure of a column of water, and confined by a stop-cock, which, when opened, permits it to escape in a slender stream from a small aperture. In a

In the year 1746, some very singular phenomena were exhibited by two or three ingenious professors in the University of Leyden; which depended on a newly discovered power of accumulating electricity. Their mode of exhibiting these effects consisted in enclosing some water in a glass vessel, and electrifying it; if then the outside of the glass vessel was grasped with one hand, and the enclosed conductor, or any substance connected with it, touched with the other, a bright spark ensued, and a violent convulsive motion was felt in the arms and across the breast.

Professor Muschenbroeck, Messrs. Cuneus, Alemand, and Winkler, made the experiment with water in glass jars or bottles; and M. Von Kliest (who it is said first made the discovery) employed a phial, in which a blunt piece of wire was loosely placed. This experiment soon became popular; the apparatus received the name of a Leyden jar, or Leyden phial; and the sensation it produced, the electric shock.*

Dr. Franklin, in accounting for these phenomena, suggested that a charged phial or jar contained no more electricity than before; that as much was taken from one side, as the other had above its natural portion; and that, to discharge it, nothing more was necessary than to make a com-

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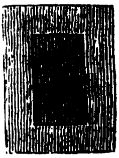
box beneath the vessel of gas an electrophorus is placed, and a wire passes through a glass tube from the upper part of this box to the opening of the stop-cock. The cover of the electrophorus is connected by a silk string with the handle of the stop-cock; so that the same motion that opens the cock, raises the cover of the electrophorus, and the spark that passes from it is conveyed by the insulated wire to the stream of gas, which it inflames.

* The first experimenters gave ludicrous and exaggerated accounts of its effects, and to this circumstance, may perhaps be partly attributed the public curiosity it so promptly and highly excited. In the same year it was shown by itinerant exhibitors in almost every part of Europe; and the experiment was repeated and varied by the electricians of every country.

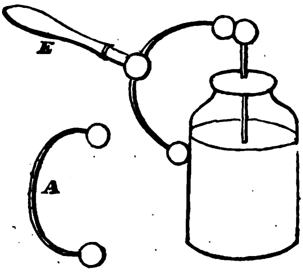
munication between the two sides; the electricity being by this means enabled to regain its equilibrium, that equilibrium was instantly restored, and no signs of electricity remained. He also demonstrated by experiments, that the electricity did not reside in the coating, as had been supposed, but in or upon the glass itself. After a phial was charged, he removed the coating, and found, that upon applying a new coating, the shock might be received. When, to any body or surface, was attributed the property, according to this theory, of having more than its usual portion of electricity, the Doctor proposed to distinguish its state by the term *plus*, or positive; when the body or surface had less than its usual share of electricity, its state was distinguished by the term *minus*, or negative. These terms answered the same end, and expressed the same things, as those of vitreous and resinous, proposed by Du Fay, but they were supposed to be so much more appropriate, that their admission into the language of the science soon became general both in England and America.

Having thus briefly explained the usually received theory of the Leyden experiment, it may now be advisable to examine the form of the apparatus best calculated to exhibit the effects of accumulated electricity. A plate of common window-glass, coated on both sides with tin-foil, is occasionally used for this purpose; though it will be evident that the metallic coating must not reach the extremity of the glass, as a conducting communication would then be formed between the two surfaces.



If we wish to increase the electrified surface, a glass cylinder or jar is employed, and a wire, projecting from the centre, is furnished with a ball which connects the

interior of the jar with the prime conductor of the machine. But the most convenient form of the jar is shown in the accompanying diagram. It is coated on the inside, and also on the outside, with tin-foil to within two inches and a half of the top. With the inside coating a wire is connected, which rises through a lid of baked wood neatly fitted into the mouth of the jar, and terminating in a smooth brass ball. The uncoated part of the jar must be kept perfectly clean and dry, otherwise the action will be very incomplete. The coating is best fastened on with very strong gum water, but some electricians use common paste; and in some instances the tin-foil is first pasted upon paper, and afterwards on the glass: this is considered an improvement, both as it respects the facility of drying the gum or paste, and also the strengthening of the jar.

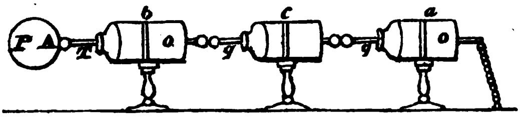


When it is wished to discharge the jar without allowing the charge to pass through the body, an instrument is used, called the discharging rod, which is composed of a bent wire A, or two branches, connected by a joint, and furnished with a glass handle E. The extremities of the rod or branches are pointed, but have screws, by means of which they are fitted with balls. In discharging a jar with this instrument, it is held by the glass handle, and, while one end is applied to the outer coating of the jar, the other is made to approach the ball of its wire, and thus the electricity passes through the metallic part of the discharger from the one coating to the other of the jar. If the extremities be without their balls, the discharge is effected without noise; but otherwise there takes place an explosion, more or less loud according as the jar is more or less charged.

Batteries of great size have been constructed by different electricians, so as to accumulate an enormous quantity of electricity, capable of melting the hardest metals, and of putting an instantaneous termination to animal life. Dr. Priestley constructed a battery consisting of sixty-four jars, and containing thirty-two square feet of coated surface. Mr. Cuthbertson completed, in 1784, for the Teylerian Museum at Haarlem, a battery of one hundred and thirty-five jars and one hundred and thirty-two feet of coated surface; and in 1789 he completed another battery for the same institution, consisting of one hundred jars, and containing five hundred and fifty feet of coated surface.

We have already noticed that the uncoated interval of the Leyden jar should be clean and dry; but this must be understood with some limitation, as, if it be perfectly clean, and so dry as to approach to warmness, an explosion will take place between the coatings over the glass, and thus occasion a loss of the charge, with a great waste of time. These effects may be prevented by breathing on the glass through a piece of barometer tube, but much more effectually by pasting a slip of writing paper, an inch broad, on the inner surface of the jar, close to the upper edge of the coating. By this means the intensity of the charge is diminished at the very spot where its tendency to explode is the greatest.

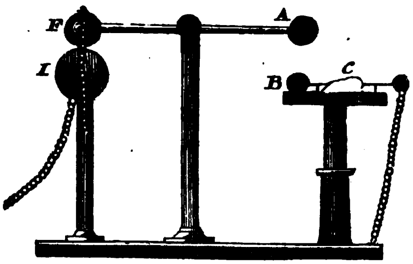
If we suspend a globular jar by its knob from the positive conductor of the electrical machine, the outer coating being insulated, no charge can be communicated to it, as the glass has only an attraction for a certain quantity of electricity, and the coatings can only be considered as conductors for its two surfaces; but if a communication be made with the ground by means of any conducting body, sparks will then be given off from the outer coating in rapid succession. Professor Brande has suggested a mode of applying this arrangement to the construction of a powerful battery; instead, however, of supporting them by the prime conductor, they are attached to glass insulating stands. This ingenious contrivance may be readily understood by reference to the annexed diagram, in which the jar *b* is connected by its ball T, with the prime conductor P A, while the outer coating *o*, communicates with the internal surface of the jar *c*; this is again connected in a similar way with the third jar *a*,—the latter jar having its outer coating *o* connected with the ground. On connecting this series in the ordinary way, after it is charged, it will be evident that a very powerful effect must be produced.



Upon this principle, several jars may be charged at once by attaching them to the prime conductor, so that the outer coating of one of the suspended jars invariably communicates with that which precedes it. Thus the ball of the first jar is attached to the prime conductor by a hook;

and a similar contrivance may then be employed to connect the internal coating of the second with the external side of the jar above it; and as the electric fluid is driven off from the first jar, it is received by the second, and so on through the entire series.

An electrometer has been constructed by Mr. Cuthbertson, which, for discharging accumulated electricity, is superior to any that has yet been described. Those only who have to go through the operation of melting wires before a public audience, can duly appreciate the value of this incomparable instrument.



The accompanying figure will best illustrate the form of the apparatus. The base consists of an oblong square piece of mahogany of about eighteen inches long, and six in breadth: in this are three glass supports, mounted with brass balls. The ball I, has a brass tube fixed to it, about three inches long, cemented to the top of the glass stand, and a hole at the top, of about half an inch in diameter, corresponding with the inside of the tube. A F, is a straight brass wire, with a knife-edged centre in the middle, placed a little below the centre of gravity, and equally balanced with a hollow brass ball at each end; the centre, or axis, resting upon the inside of the central ball, a light balance weight being fitted to the wire.

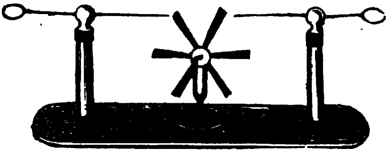
It is obvious, from the construction of the apparatus, that if the foot stand horizontally, and the ball F be made to touch I, it will remain in that position without the help of the weight; and if it should receive a low charge, the two balls will repel each other; F will begin to ascend, and, on account of the centre of gravity being above the centre of motion, the ascension will continue till A rest upon B. If the balance be again set horizontally, and the sliding weight be brought towards F, it will bring F back to I, with a pressure equal to that weight, so that more electricity must be communicated than formerly, before the balls will separate; and, as the weight at F is increased or diminished, a greater or less quantity of electricity will be required to effect a separation.

When this instrument is to be used with a jar, or battery, one end of a wire or chain must be inserted into the ball L, and the other end into a hole of any ball proceeding from the inside of a battery or jar, and when the electrical repulsion becomes sufficiently energetic to overcome the weight, a communication will be formed with the ball at B, and the inflammable body *c* inflamed. The communication between the ball F and the prime conductor being kept up after the ball F, leaves I, by means of a small loose wire within.

A variety of attempts have been made to mark the precise direction of the electrical current which results from destroying the equilibrium of any two bodies. If we take a Leyden jar that has been rendered slightly damp by being breathed upon, and place it with its knob in contact with the positive conductor of an electrical machine in a darkened room, when the jar is charged, and the action of the machine continued, the electricity will appear to pass from the internal to the external coating over the uncoated interval in luminous streams, like water overflowing from the top of a vessel kept constantly supplied. If the jar be removed, and its knob placed against the negative conductor, the stream will obviously change its direction. A degree of dampness on the uncoated part of the glass is necessary in this experiment, to prevent the discharge of the jar by a spontaneous explosion, in which case the fluid passes too rapidly from one surface to the other to allow the observer to ascertain its direction. If the moisture be not sufficient, diverging brushes of light will occasionally pass from the positive surface, instead of the continuous streams abovementioned.

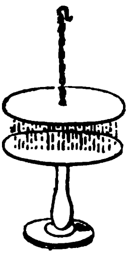
If a light wheel, the vanes of which are made of fine card-paper, be made to turn freely on its axis, a stream of electricity from a pointed wire fixed in the conductor will give it motion; and it will move from the electrified point, whether its electricity be positive or negative. In this experiment, the current seems to be produced by the recession of the similarly electrified air in contact with the point; and, therefore, the circumstance of the wheel turning in the same direction when the electricity is negative, cannot be considered as a proof of the existence of a double current of the electric fluid.

But the most satisfactory exhibition of the course of the electric fluid, or air, from the positive to the negative conductor, is afforded by an experiment contrived by Mr. Singer, and which he considered as removing all difficulties on the subject. "It has," observes he, "been long known that a light float-wheel, made by inserting several vanes of card in the periphery of a cork that is made to turn freely on a pin or centre, will be put in motion by presenting it to an electrified point; and the motion of the wheel being always from the point, whether that point was positive or negative, has been occasionally urged as an argument for a double current of the fluid; although it is evident, from what has been already stated, that a point either positive or negative must produce a current, by the recession of the air opposed to it, when similarly electrified by its contact, which is fully adequate to the production of these effects. Conjecturing that the currents of electrified air would not take place in this manner if the points were opposed to each other, the following arrangement was made."



A light float-wheel is shown above, which being mounted so as to turn freely between two upright wires, was placed on an insulated stem, and introduced between the pointed wires of Henley's discharger, which was placed accurately opposite to each other, and at the distance of rather more than an inch from the upper vanes of their respective sides. On connecting one of the wires with the positive conductor of the machine, and the other with the negative conductor, and turning the machine, the wheel will move in a direction from the positive to the negative wire. On reversing the connexions, so that the wire which was negative may become positive, and that which was positive be made negative, the motion of the wheel will be reversed; for it will still move from the positive to the negative wire.

The attraction and repulsion of air that has been electrified by contact with the prime conductor of the electrical machine may readily be exhibited by the following simple apparatus. Suspend from the conductor, by a brass chain, a circular plate of copper, reaching to within an inch and a half or two inches of the table. Directly under this plate place another of the same form, and a little larger, on the table. Turn the machine, and the fluid will pass from the upper to the lower plate. If small figures cut out of pasteboard, or pith of elder, be introduced between the plates, they will dance about with apparent vivacity, and sometimes appear to course round the edge of the lower plate, This experiment is illustrated in the accompanying diagram.



The *electrical bells* furnish a pleasing illustration of the attraction and repulsion of the electric matter. They are usually three in number. The two outer bells are suspended by brass chains; the middle bell and the two clappers by fine silk threads. When the bells are attached to the conductor, and the machine is turned very gently, the fluid will pass along the chains to the two outer bells, but will not pass along the silk to the clappers and middle bell. Thus the outer bells, being charged with an extra quantity of fluid, will attract the clappers; but the moment they touch the bells they become charged, and are repelled with such force as to cause them to strike against the middle bell, on which they deposit their electricity, and are again attracted. By this means a constant ringing is kept up while the machine is turned. From the inside of the middle bell, a brass chain passes to the table, for the purpose of conveying away the fluid deposited on it by the clappers.

When a powerful electric charge is passed through a slender iron wire, the wire is ignited or dispersed in red-hot balls. Very large batteries were formerly considered essential to the production of this effect; but if the wire be sufficiently thin, a single jar, exposing a coated surface of about one hundred and ninety square inches, will sufficiently exemplify it. The finest flat steel wire is best calculated for the purpose. Cuthbertson's balance electrometer should always be employed to regulate the charge: the circuit from the inner to the outer surface of the jar should be as short as possible; and the wire intended to be melted, placed in a right line, and confined at the ends between small wire forceps.

Dr. Franklin performed some pleasing experiments on the fusing of metals, which may be thus imitated:—Take three pieces of window-glass, each one inch wide, and three inches long, and place them contiguous to each other, with two narrow strips of gold-leaf between them, so that the middle glass may have, on each side of it, a strip of gold, with its ends projecting a little beyond the glass. Let the whole be properly secured within the press of the universal discharger; pass the charge of a large jar through the strips of gold, they will be melted and driven into the glass. The outer pieces of glass are generally broken, but the middle piece is often left entire, and is marked with an indelible metallic stain on each of its surfaces.

The colours produced when metals are thus fused, either on glass or paper, are sometimes exceedingly beautiful, and have been in some cases employed in impressing letters, and ornaments of various kinds, on silk and paper. The process observed in such cases, Mr. Singer thus describes in his Elements:—" The outline of the required figure is first traced on thick drawing-paper, and afterwards cut out in the manner of stencil plates. The drawing-paper is then placed on the silk or paper intended to be marked; a leaf of gold is laid upon it, and a card over that; the whole is then placed in a press, or under a weight, and a charge from a battery sent through the gold leaf. The stain is confined, by the interposition of the drawing paper, to the limit of the design; and in this way, a profile, a flower, or any other outline figure, may be very neatly impressed."

A single spark may be made to perforate a strong glass tube by the following simple process: fill a small phial with olive oil, and insert into it a pointed wire bent at right angles, so that by sliding through a cork fixed in the neck of the phial, the point of the wire may rest against any part of the inside beneath the oil: attach the phial by its wire to the conductor of the machine, and bring the knuckle or a brass ball near the outside of the phial, opposite to the point of the wire within it; a spark will pass from the point to the knuckle, and make a small hole in the glass.

Almost all inflammable substances may be kindled by means of electricity. The common method of kindling resin by the electric spark, is to pulverise it, and sprinkle the powder on some dry cotton wool. Thus, if a small quantity of flax, or of cotton wool, be loosely tied on one of the knobs of the discharging rod, and a little finely-powdered resin sprinkled on it, and a jar be discharged by bringing the end of the rod thus prepared in contact with the knob of the jar, the charge will pass through the flax, or wool, and in so doing will melt and ignite the resin, and set the whole on fire.

The decomposition of water by electricity was first effected by Van Troostwyk and Deiman, assisted by Mr. Cuthbertson; this they effected by means of a complicated apparatus, and a very tedious process. Their method of procedure was improved on by Dr. Pearson, and after him by Mr. Cuthbertson: but the most simple form of an apparatus for this purpose is that of Dr. Wollaston. This apparatus is thus constructed:—Two finely pointed wires of gold or platina are inserted into capillary tubes; each wire is thrust into the tube till it nearly reaches the end of it, and the glass is softened by heat until it adheres to the wire and covers its point. The glass is then carefully ground away, till the point of the wire can be seen by the help of a magnifying glass. One of these wires is made to communicate with the ground, or with the negative conductor of the machine, and the other with an insulated ball placed near the positive conductor; the two points are placed near each other in a vessel of water: when a current of sparks is discharged through the wires, a series of minute bubbles of gas will rise from the points of the gold wires, and, when collected in an inverted receiver, will explode on the application of a lighted taper. Dr. Wollaston found by experiment, that a point 1-700th of an inch in diameter, decomposed the water, when the spark which passed from the conductor to the insulated ball was 1-8th of an inch in length; and that a point 1-1500th of an inch in diameter produced the same effect, when the sparks were only 1-20th of an inch in length. Hence the rapidity of the decomposition was in proportion to the limited size of the point of the wire.

To show the passage of the electric light, we may employ an instrument composed of a glass tube closed with two brass caps. This tube has a spiral row of small round pieces of tin-foil attached to its outer surface, and lying at about 1-13th of an inch from each other. If this instrument be held by one of its extremities, and its other extremity be presented to the prime conductor, every spark that it receives from the prime conductor will cause small sparks to appear between all the round pieces of tin-foil, and this in the dark affords a pleasing spectacle, the instrument appearing encompassed by a spiral line of fire. The small round pieces of tin-foil are at other times attached to a flat piece of glass, so as to represent curve lines, flowers, letters, &c. and they may be illuminated in the same manner as the spiral tube.

The colour of the electric spark seems to depend on the density of the medium through which it is made to pass. This is proved by the following experiments :—Fix with cement a short iron or platina wire at one end of a glass tube thirty inches long, so that the wire may project a little way within the tube, and fix a small brass ball on the outer extremity of the wire. Fill the tube with mercury, and at the open end place a drop of ether, which may be secured by the point of the finger while the tube is inverted in a vessel of mercury, so as to form a Torricellian vacuum in the upper part. The ether will rise to the top; and upon the removal of the finger, and the fall of the mercury, will expand into vapour. If now electricity be transmitted through this vapour, it will be rendered luminous, and assume various hues according to its strength. When the spark is strong, and has to pass through some inches of the expanded vapour, the light is usually of a beautiful green colour. Take an air-pump receiver twelve or fourteen inches high, and six or seven inches in diameter; adapt a wire, pointed at its lower extremity, to the top of the receiver, letting the point project about two inches into its inside; place the receiver on the plate of the air-pump, and electrify the wire at its top positively; whilst the air remains in the receiver, a brush of light of very limited size only will be seen, but in proportion as the air is withdrawn by the action of the pump it will enlarge, varying its appearance, and becoming more diffused as the air becomes more rarefied; until at length the whole of the receiver is filled by beautiful coruscations of light, changing their colour with the intensity of the transmitted electricity. Another pleasing experiment may be noticed:—Into a piece of soft deal about three inches long and an inch and a half square, insert two pointed wires obliquely at nearly an inch and a half distance from each other, and to the depth of an eighth of an inch; the wires should incline in opposite directions, and the track between the points be in that of the fibres; a spark, in passing from one point to another through the wood, will assume different colours, in proportion as it passes more or less below the surface; and by inserting one point lower than the other, so that the spark may pass obliquely through different depths, all the prismatic colours may be made to appear at once. Sparks taken through balls of wood or ivory appear of a crimson colour; those from the surface of silvered leather are of a bright green; a long spark taken over powdered charcoal is yellow; and the sparks from imperfect conductors have a purple hue. The quantity of air through which these sparks are seen also influences their appearance; for the green spark in the vapour of ether appears white when the eye is placed close to the tube, and reddish when it is viewed from a considerable distance.

ATMOSPHERIC ELECTRICITY.

Identity between Lightning and Artificial Electricity.—Experiments by Franklin, Monnier, and Mazeas.—Electric Kite.—Results by Cavallo.—Phenomena of a Thunder-Storm. —Atmospheric Electrometer. — Best Mode of Protecting Buildings.—Thunder and Powder Houses. — Electric Light in Rarefied Air. — Aurora Borealis.—Shooting Star.

We have now to notice the analogy that subsists between atmospheric electricity, or lightning, and that produced by artificial means. The following may be considered as an outline of Dr. Franklin's observations on this important branch of the science. He commences by observing that "The zig-zag appearance of the natural lightning is exactly the same as that of a strong electric spark when it passes through a considerable interval of air. Lightning generally strikes such bodies as are high and exposed, as the summits of hills, the tops of lofty trees, high towers, and spires; while the electric fluid is always received by the most prominent parts, when striking from one body to another. Lightning is observed to strike most frequently into those substances that are good conductors of electricity, such as metals, water, and moist substances; and to avoid those that are non-conductors. Lightning inflames combustible bodies. The same is effected by electricity. Metals are melted by a powerful charge of electricity: this phenomenon is one of the most common effects of a stroke of lightning. Lightning destroys animal life. The magnetic needle is effected in the same manner by lightning and by electricity, and iron may be rendered magnetic by both causes. The phenomena are, therefore, strictly analogous, and differ only in degree; and if an electrified gun-barrel will give a spark, and produce a loud report at two inches distance, what effect may not be expected from perhaps 10,000 acres of electrified cloud?"

Reasoning from these facts, Franklin formed the design of erecting a conducting-rod by which the lightning might be drawn from the clouds, and thus afford an opportunity of ascertaining its identity with the electric fluid. "The electric fluid," said he, "is attracted by points; we do not know whether this property be in lightning; but since they agree in all the particulars in which we can already compare them, it is not improbable that in this they likewise agree. Let the experiment be made." While the American philosopher was waiting for the erection of a spire in Philadelphia, his opinions became known, and he was anticipated by D'Alibard and De Loe, who erected a rod such as Franklin had suggested, in France, and succeeded in the experiment.

The earliest useful observations that were made on the electrical state of the atmosphere in Europe, appear to have been those of Monnier; his experiments were performed with an apparatus, which consisted of a pole thirty-two feet in height insulated in a piece of turf, having at its top a strong glass tube, to which a tube of tinned iron was attached, and which terminated in a point. About the middle of this tube there was fastened a fine iron wire about fifty lines long, which, without touching any other body, was connected with a silk cord stretched horizontally. He found that, although the atmosphere was constantly electrified more or less, yet that in dry weather the electricity increased from sunrise, when it was weakest, till about four o'clock in the afternoon, at which time it was strongest, gradually diminishing from that time till the dew began to fall, after which it diminished till midnight.

The Abbé Mazeas made several observations with an atmospherical apparatus, consisting of an iron wire three hundred and seventy feet long, raised about ninety feet from the ground, and properly insulated. The results of his experiments with this instrument were the following:—In very dry weather the wire readily attracted light bodies, if brought within three or four lines of it; and, if the weather was not stormy, the electricity of the air was about half as great as that of a stick of sealing-wax two inches long. When he grasped the wire in his hand, the signs of electricity disappeared entirely, and did not return till after an interval of three or four minutes. He also found that the electricity of the atmosphere was not increased with storms and hurricanes unattended with rain; for during a violent storm of wind, which continued uninterruptedly for three days, in the month of July, he found it necessary to place the dust within four or five lines of the conductor, before it exhibited a sensible attraction. No change was produced by the different directions of the winds. In the driest nights of summer he never could observe any electricity in the air, but it began to appear in the morning at sunrise, and vanished in the evening at about half an hour after sunset. In the month of July, on a very dry day, when the sky was serene, and the heat intense, he found the electricity stronger than he had ever observed it. The dust was then attracted at the distance of ten or twelve lines from the conductor.*

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* Experiments connected with atmospheric electricity, were now performed by the philosophers in nearly every part of Europe, and the

Having thus briefly noticed the effects of metallic rods for conveying the electricity of the atmosphere to the earth's surface, it may now be advisable to advert to another agent, which, although somewhat more complicated than the conducting wire, was yet found, in the hands of Dr. Franklin, a most efficient piece of apparatus. It consists in the elevation of a long conducting string by means of a windsail or kite.

An *electrical kite* should be constructed in the most simple manner, as it is an apparatus very liable to be injured or lost. In dimensions it should not exceed four feet in height, by two feet wide. This will be found the most manageable size, and it is necessary to varnish it with drying oil to defend it from the rain. The string must be furnished with a thin copper or silver thread interwoven through its whole length; that which is employed in the fabrication of gilt lace appears best adapted to the purpose.

When the kite is raised, the string is insulated by attaching to it a silk cord, whose opposite extremity may be

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following unfortunate catastrophe will show that they were not always unattended with danger. On the 6th of August, 1753, Professor Richman, of Petersburgh, was making experiments on lightning drawn down a metal rod into his own room. He had provided himself with an instrument for measuring the quantity of electricity communicated to his apparatus, and as he stood with his head inclined to it, Solokou, an engraver, who was near him, observed a globe of blue fire, as large as his hand, pass from the instrument towards his head. The Professor was struck lifeless, and his assistant was also much hurt. The latter could give no very minute account of the way in which he was affected; for at the time the Professor was struck, he stated there arose a sort of vapour which entirely benumbed him, and made him sink down to the ground, so that he could not even remember to have heard the clap of thunder which followed. The globe of fire was attended with an explosion like that of a pistol; the instrument for measuring the electricity was broken to pieces, and the fragments thrown about the room.

fastened to a rail, or any other fixed place. The end of the metallic string may then be connected with a prime conductor similar to that employed in the common electrical machine; and with this the experiments may be performed.

To ensure the safety of the operator, which is a very important consideration in this otherwise dangerous experiment, it will only be necessary to connect a brass rod with the earth, and bring the other end within about two inches of the prime conductor, so that in the event of the kite coming in contact with a large electrical cloud, a ready passage will thus be found for the electric fluid to the earth. In raising or lowering the kite, shocks are frequently taken: this, however, may be effectually prevented, by suffering a part of the string between the operator and the kite, to bear constantly against the brass ball that is connected with the ground; and this precaution is more particularly essential when thunder-clouds are over-head.

Mr. Cavallo, from a variety of experiments made with electrical kites, furnishes the following results, which will be found correct in the generality of cases. "The air appears to be electrified at all times: its electricity is constantly positive, and much stronger in frosty than in warm weather; but it is by no means less in the night than in the daytime. When it rains, the electricity of the kite is generally negative, and very seldom positive. The aurora borealis seems not to affect the electricity of the kite. The electric spark taken from the string of the kite, or from any insulated conductor connected with it, especially when it does not rain, is very seldom longer than a quarter of an inch; but it is exceedingly pungent. When the index of the electrometer is not higher than 20°, the person who takes the spark will feel the effect of it in his legs; as it appears more like the discharge of an electric jar, than the spark taken from the prime conductor of an electrical machine The electricity of the kite is generally stronger or weaker, according as the string is longer or shorter; but it does not keep any exact proportion to it. The electricity, for instance, brought down by a string of one hundred yards, may raise the index of the electrometer to twenty; when, with double that length, the index of the electrometer will not go higher than twenty-five."

The phenomena incident to a thunder-storm are always beheld with the most intense interest by the student in this science; and although many very poetical descriptions of its effects are on record, the facts furnished by the Italian philosopher Beccaria are as illustrative as any.

"Thunder-storms," says Beccaria, "generally happen when there is little or no wind; and their first appearance is marked by one dense cloud, or more, increasing very fast in size, and rising into the higher regions of the air; the lower surface black, and nearly level, but the upper finely arched, and well defined. Many of these clouds seem frequently piled one upon another, all arched in the same manner; but they keep continually uniting, swelling, and extending their arches.

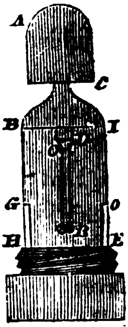
"At the time of the rising of this cloud, the atmosphere is generally full of a great number of separate clouds, motionless, and of odd and whimsical shapes. All these, upon the appearance of the thunder-cloud, begin to move towards it, and become more uniform in their shapes as they approach; till, coming very near the thunder-cloud, they mutually stretch towards one another, immediately coalesce, and together make one uniform mass. But sometimes the thunder-cloud will swell, and increase very fast, without the conjunction of these adventitious clouds, the vapours of the atmosphere forming themselves into clouds wherever it passes. Some of the adventitious clouds appear like white fringes at the skirts of the thunder-cloud, but these are continually growing darker and darker as they approach or unite with it.

"When the thunder-cloud is grown to a great size, its lower surface is often ragged, particular parts being detached towards the earth, but still connected with the rest. Sometimes the lower surface swells into various large protuberances, bending uniformly towards the earth. When the eye is under the thunder-cloud, after it is grown larger, and well formed, it is seen to sink lower, and to darken prodigiously; at the same time that a number of adventitious clouds (the origin of which can never be perceived) are seen in rapid motion, driving about in every direction under it. While these clouds are agitated with the most rapid motions, the rain generally falls in the greatest plenty; and, if the agitation is exceedingly great, it commonly hails."

While the thunder-cloud is swelling, and extending its branches over a large tract of country, the lightning is seen to dart from one part of it to another, and often to illuminate its whole mass. When the cloud has acquired a sufficient extent, the lightning strikes between the cloud and the earth, in two opposite places, the path of the lightning lying through the whole body of the cloud and its branches. The electrical explosion generally takes place in the air, and at a considerable height; but in many instances it happens between the clouds and the earth. In most instances, perhaps, the lightning descends from the clouds to the earth, and the explosion is then called the descending stroke; but in some cases it is known to pass from the earth to the clouds, and is then termed the ascending stroke: of the latter kind appears to have been the explosion which took place on the Malvern Hills, in the summer of 1826, and which was attended with such melancholy consequences. A very curious instance of the ascending stroke is related by G. F. Richter, in his work on thunder. He informs us, that in the cellar belonging to the Benedictine monks of Fontigno, while the servants were employed in pouring into a cask some wine which had been just boiled, a fine light flame appeared round the funnel, and they had scarcely finished their operation, when a noise like thunder was heard: the cellar was instantly filled with fire; the cask was burst open, although hooped with iron; the staves were thrown with prodigious violence against the wall; and, on examination, a hole of three inches diameter was found in the bottom of the cask.

A portable electrometer is essential for observing the electrical state of the atmosphere, for meteorological purposes. Electrometers constructed of pith of elder were employed by Mr. Cavallo in many of his experiments. The case, or handle, of one of these instruments must be formed of a glass tube, about three inches in length, and three-tenths of an inch in diameter, one half of which is coated with wax on the outside. From one extremity of this tube a small loop of silk proceeds, which occasionally serves to support the electrometer. To the other extremity of the tube a cork is adapted, which, being cut tapering on both ends, can fit the mouth of the tube with either end. From one extremity of this cork two linen threads proceed, a little shorter than the length of the tube, each of which support a little cone of pith. When this electrometer is to be used, that end of the cork which is opposite to the threads is pushed into the mouth of the tube; the tube then forms the insulated handle of the instrument. But when the electrometer is to be carried in the pocket, the threads are put into the tube, and the cork stops it.

Mr. Cavallo also constructed another portable electrometer for atmospherical purposes, which deserves particucular notice. Its principal part consists of a glass tube B I O G, as represented in the accompanying figure, cemented at the bottom into the brass piece H E, by which part the instrument is to be held when used for the atmosphere. The upper part of the tube is tapered, and entirely covered with sealing-wax; to this tapering part a small tube is cemented; the lower extremity, being also covered with sealing-wax, projects a short way within the large tube.



Into this smaller tube a wire is cemented, which with its under extremity touches the flat piece of ivory D, fastened to the tube by means of a cork; the upper extremity of the wire projects about a quarter of an inch above the tube, and screws into the brass cap A C, which cap is open at the bottom, and serves to defend the waxed part of the instrument from moisture.

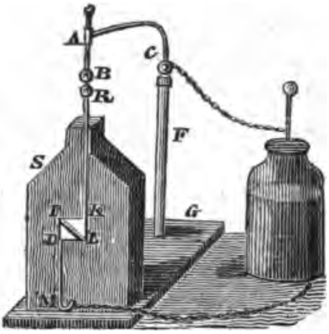
The conical corks, or balls, B, which show the electricity by their repulsion, are made very small, and suspended by very fine silver wires, shaped like rings at the top, by which they hang very loosely on the flat piece of ivory, which has two holes in it. By this method of suspension, which is applicable to every sort of electrometer, the friction is reduced to almost nothing, and the instrument is thus rendered sensible to a very small degree of electricity. O E and G H are two narrow slips of tin-foil, fixed on the inside of the glass, and communicating with the brass bottom H E. They serve to convey that electricity which, when the balls touch the glass, is communicated to it, and, being accumulated, might disturb the free motion of the balls.

To try the electricity of the atmosphere by this electrometer, the electrician must unscrew it from its case, and hold it by the bottom H E; thus presenting it to the air a little above his head, so that he may conveniently see the balls, which will immediately diverge if there is any electricity; whether this be positive or negative, may be ascertained by bringing an excited piece of sealing-wax, or other electric, towards the cap.

M. Saussure has made an improvement in this electrometer. The principal circumstances in which his electrometer differs from Mr. Cavallo's are: The fine wires, by which the balls are suspended, should not be so long as to reach the tin-foil which is pasted on the inside of the glass; because the electricity, when strong, will cause them to touch this tin-foil twice consecutively, and thus deprive them in a moment of their electricity. To prevent this defect, and yet give them a sufficient degree of motion, it is necessary to use larger glasses than those that are generally applied to Mr. Cavallo's electrometer; two or three inches diameter will answer the purpose very well. But, as it is necessary to carry off the electricity which may be communicated to the inside of the glass, and which may be confounded with that which belongs to those substances that are under examination, four pieces of tin-foil should be pasted on the inside of the glass; the balls should not be more than 1-20th of an inch diameter, suspended by silver wires, moving freely in holes nicely rounded. The bottom of the electrometer should be of brass; for this renders it more easy to deprive them of any acquired electricity, by touching the bottom and top at the same time.

For common purposes, and occasional observations, very simple contrivances may be employed. A common jointed fishing-rod, having a glass stick covered with sealing-wax substituted for the smallest joint, may be occasionally projected from the upper window of a house. A pair of pith-balls must be attached to a cork, in which the end of the glass stick is thrust; and this part of the apparatus is to be occasionally uninsulated, by placing a pin in the cork, connected with a thin wire held in the hand. In this uninsulated state, the fishing rod and its attached electrometer are to be held for a few seconds projecting from the window, and, whilst in this position, the pin is to be withdrawn by pulling the thin wire; this insulates the electrometer, which may be then drawn in and examined. Its electricity will be found to be contrary to that of the atmosphere.

The best mode of protecting buildings by reference to experimental data may now be examined.



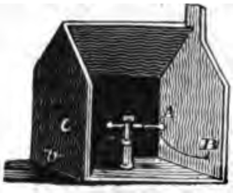
The simplest form in which these experiments are made, is that known by the name of the *thunder-house.* This is represented in the preceding page, where S is a board about three quarters of an inch thick, and shaped like the gable-end of a house. It is fixed perpendicularly upon the base G, from which rises the perpendicular glass F. A square hole, I L D K, about a quarter of an inch deep, and nearly one inch wide, is made in the board S, and fitted with a square piece of wood, nearly of the same dimensions. This board must fit in rather easily, so that the slightest shaking may throw it out. A wire, L I, is fastened diagonally to this square piece of wood. Another wire, R K, of the same thickness, having a brass ball R, screwed on its pointed extremity, is fastened upon the board; so also is the wire D M, which is formed into a hook at M. From the upper extremity of the glass pillar, F, a crooked wire proceeds, having a spring socket A, through which a double-knobbed wire slides perpendicularly, the lower knob B of which falls just above the knob R. The glass pillar must not be fixed very tightly into the bottom board; but so as to be easily moved round its own axis, by which means the brass ball B may be brought nearer or farther from the ball R. When the square piece of wood is fixed into the hole so that the wire stands from K D, then the metallic communication is continuous, and the instrument represents a house furnished with a proper metallic conductor; but if the square piece of wood is fixed so that the wire stands in the direction I L, as represented in the figure, then the metallic conductor from the top of the house to its bottom, is interrupted, and mischief may result.

Fix the piece of wood, so that its wire may be as represented in the figure, in which case the metallic conductor is discontinued. Let the ball B be fixed at about half an inch perpendicular distance from the ball R; by means of a chain connect the wire *e* with the wire of the jar, and let another chain, fastened to the hook M, touch the outside coating of the jar. Connect the wire C with the prime conductor, and charge the jar; then, by turning the glass pillar, let the ball B come gradually towards the ball R, and when they are arrived sufficiently near one another, the jar will explode, and the piece of wood be driven out of the hole to a considerable distance from the thunder-house. In this experiment the ball B represents an electrified cloud; which, when it is arrived sufficiently near the top of the house, the electricity strikes; and, as this house is not secured with a proper conductor, the explosion breaks part of it, as is seen by the violent removal of the piece of wood.

Unscrew the brass ball B from the wire, so that it may remain pointed. With this difference only in the apparatus, repeat the above experiments, and it will be found that the piece of wood is not in neither case moved from its place, nor will any explosion be heard; which not only demonstrates the preference of the conductors with pointed terminations to those with obtuse ends; but also shows that a house furnished with sharp terminations, although not furnished with a regular conductor, is almost sufficiently guarded against the effects of lightning.

In the same way, a model of a powder-mill may be blown up, or a house be set on fire, by making an interrupted circuit within them, and placing gunpowder, or other combustible matter in its interval, as is shown in the model on the next page.

The house is supported by a mahogany base *v*, and one side is removed to show the internal construction. The wire and ball A enters the central pillar, which is furnish-



ed with a cavity to contain the gunpowder. The chain passing through the end of the house at B, communicates with the external surface of a charged jar, while a similar chain may be made to pass through a hole at C, and form a conducting line with another wire and ball entering the central stem opposite A. On passing the spark through the edifice, the gunpowder is ignited, and the walls thrown down.

The following precautionary hints may be offered, as they comprise the best modes of ensuring safety during a thunder-storm.

Shelter should not be taken under trees or hedges, for, should they be struck, such situations are particularly dangerous; at the same time a person is much safer at about thirty or forty feet from such objects than at a greater distance, as they are likely to operate as conductors. Large portions of water also ought to be carefully avoided, and even smaller streams that may have reulted from recent rain, as these are good conductors, and the height of a human being connected with them, may sometimes determine the course of the lightning. In a house the safest situation is considered to be the middle of the room; and this situation may be rendered still more secure by standing on a glass-legged stool: but, as such an article is not in the possession of many people, a hair mattress, or a thick woollen hearth rug makes a very good substitute. It is very injudicious to take refuge, as some persons do, in the cellar during a thunder-storm, since the discharge is often found to be from the earth to the clouds, and many instances are recorded of buildings that were struck having sustained the greatest injury about the basement story. But whatever situation is chosen, the greatest care should be taken to avoid any approach to the fire-place, since the chimneys are most likely to attract the fluid, and even if there be no fire in the grate at the time, it should be remembered that soot is a powerful conductor. The same caution is necessary with respect to all large metallic surfaces; as gilt furniture, or bell wires.

The distance of the thunder-cloud may readily be determined, as the interval between the flash and the commencement of the report furnishes the data necessary for the calculation. According to Flamstead, sound travels at the rate of 1142 feet in a second: consequently, by a watch which points the seconds, the distance of the cloud is easily ascertained, for the flash and the sound are really contemporaneous; and the former requires hardly any perceptible lapse of time to travel through any ordinary distance. Thus, for example, suppose the flash to occur five seconds before the sound is heard, then 1142 × 5=5710=1 mile 430 feet, the distance of the explosion from the place of the observer. So far this calculation is very gratifying, but it is no criterion of safety, for it only indicates the distance of a discharge that has taken place: the next may render the observer incapable of observation.

The *aurora borealis*, or northern lights, are generally considered to arise from the passage of electricity through highly rarefied air, and the mode of producing these diffused luminous streams has already been pointed out; it may however be advisable to notice Mr. Dalton's account of this splendid phenomenon. It occurs in his Meteorological Essays.

"Attention," says Mr. Dalton, "was first excited by a remarkably red appearance of the clouds to the south, which afforded sufficient light to read by, at eight o'clock in the evening, though there was no moon, nor light in the north. Some remarkable appearance being expected, a theodolite was placed to observe its altitude, bearing, &c.

"From half past nine to ten o'clock P. M., there was a large, luminous, horizontal arch to the southward, almost exactly like those which we see in the north; and there were some faint concentric arches northward. It was particularly noticed that all the arches seemed exactly bisected by the plane of the magnetic meridian. At half past ten o'clock streamers appeared very low in the south-east, running to and fro from west to east; they increased in number, and began to approach the zenith apparently with an accelerated velocity; when all on a sudden the whole hemisphere was covered with them, and exhibited such an appearance as surpasses all description. The intensity of the light, the prodigious number and volatility of the beams, the grand intermixture of all the prismatic colours in their utmost splendour, variegating the glowing canopy with the most luxuriant and enchanting scenery, afforded an awful, but at the same time a most pleasing and sublime spectacle. Every one gazed with astonishment; but the uncommon grandeur of the scene only lasted about one minute; the variety of colours disappeared, and the beams lost their lateral motion, and were converted into the usual flashing radiations; but even then it surpassed all other appearances of the aurora, in that the whole hemisphere was covered with it.

"Notwithstanding the suddenness of the effulgence at the breaking out of the aurora, there was a remarkable regularity in the manner. Apparently a ball of fire ran along from east to west, and the contrary, with a velocity so great as to be barely distinguishable from one continued train, which kindled up the several rows of beams one after another: these rows were situated before each other with the most exact order, so that the bases of each row formed a circle crossing the magnetic meridian at right angles; and the several circles rose one above another in such sort, that those near the zenith appeared more distant from each other than those near the horizon, a certain indication that the real distances of the rows were either nearly or exactly the same."

The aurora borealis, or, as the same appearance is commonly termed, streamers, and in the Shetland Isles, the merry dancers, can seldom be seen in the southern parts of the kingdom; and, even when seen there, the appearance is far less brilliant than in northern latitudes, where this wonderful phenomenon is the constant attendant of clear evenings, affording a great relief to the inhabitants, amid the gloom that would otherwise attend their dreary winter nights.

Now between these appearances and those of electricity, under certain circumstances, there are several points of close resemblance. For it is found by a simple experiment that, when the electric fluid is made to pass through rarefied air, it exhibits a diffused luminous stream, which has all the characteristic appearances of the northern lights. There are to be seen the same varieties of colour and intensity, the same undulating motion and occasional coruscations; the streams exhibit the same diversity of character, at one moment minutely divided into ramifications, and at another beaming forth in one body of light, or passing in well-defined flashes; and, when the rarefaction is high, various parts of the stream assume that peculiar glowing colour which occasionally appears, and which, on the whole, leaves but little room to doubt that the phenomena are produced by the passage of electricity through the upper regions of the atmosphere.

The next form of atmospherical electricity that claims our attention is that which it assumes in those meteors, to which the vulgar name of falling, or shooting stars, has been given. The aurora borealis, we have said, is caused by streams of the electric fluid passing rapidly through the higher regions of the air; and these phenomena of which we are now speaking, are, in all probability, portions of the same matter moving through a more resisting medium, since they are always observed to be at comparatively small altitudes.

These meteors vary considerably in their size and colour, and also in the rapidity of their motion; they move in various directions, but chiefly incline towards the earth. They occur in different states of the atmosphere, but prevail most in clear frosty nights, and at other times when the winds are easterly, and the sky clear; in the intervals also of showery weather they are frequent, and on summer evenings, when well defined clouds are seen floating in a clear atmosphere.

A tall glass tube connected with the air-pump is well calculated to exhibit this phenomenon; instead, however, of employing the mere spark as in the aurora borealis, it is in this case necessary to employ a Leyden jar, and transmit the charge through the vacuous tube. Large masses of fire varying in colour, and dependent on the state of the vacuum may thus be made to dart along a tube more than five feet in length.

VOLTAIC ELECTRICITY.

Discoveries by Galvani.—Muscular Motion produced by Electricity.—Invention of the Voltaic Pile.—Method of exhibiting the Electricities of Metals.—Combination of Plates.—Phenomena of Decomposition.—Medical application of Electricity.

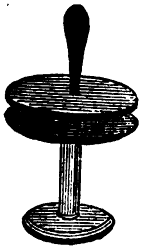
This science may be said to owe its origin to the discoveries of an ingenious Italian philosopher, named Galvani, who published a Latin treatise on the subject at the close of the last century.

In the preceding sections, the various phenomena resulting from the friction of dry bodies have been examined, which, by their mutual action on each other, tend to destroy their electrical equilibrium; and it may now be advisable to examine that branch of electricity which has led to some of the most important discoveries and splendid triumphs connected with the progress of chemical science.

In the year 1790, Galvani, professor of anatomy at Bologna, accidentally discovered that the passage of a small quantity of electricity, through the nerve of a frog that had been recently killed, had the property of exciting distinct muscular contractions. He produced the same effect with atmospherical electricity; and afterwards by the mere contact of two different metals. His discoveries were published in 1791: he proved the phenomena to be electrical, and says, "If you lay bare the sciatic nerve of a frog, and remove the integuments, then place the nerve on a piece of zinc, and a muscle on a plate of gold, and connect these metals by any conducting substance, contractions are produced; but, if non-conductors are used to connect the metals, contractions are not excited." The experiments of Galvani received considerable attention; and they were varied and extended with the greatest perseverance by Professor Volta, Dr. Valli, Humboldt, Fowler, Monro, and Robison.

The effects obtained in the experiments of these naturalists may be illustrated by very simple apparatus. The most important facts they establish are, first, that the passage of a small quantity of electricity through the nerve or nerves of any animal, occasions a tremulous motion or contraction of the contiguous muscles, and sometimes an extension of the limbs. This effect takes place both in living animals and such as have been recently killed, and even in the detached limbs of these last. It is produced when the transmitted electricity is too weak to affect the most delicate electrometers, and obtains in all animals for some time after death; their susceptibility being greatest at first, and gradually diminishing as the limbs stiffen. Animals with cold blood, as frogs and fishes, retain the power of action after death longer than others, sometimes for many hours, or even days.

When an insulated plate of zinc is brought into contact with one of copper or silver, it is found, after removal, to be positively electrical, and the silver or copper is left in the opposite state. With the accompanying simple apparatus, the above fact may be experimentally illustrated. If we take any other series of metals, the same law will be found to hold good; and if we take platinum, gold, silver, mercury, copper, iron, tin, lead, and zinc, placing them in the order in which they have been enume-



rated, each will be negative by comparison with the one that precedes it.

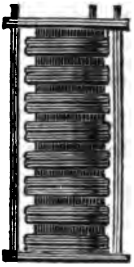
When several pairs of plates with discs of moistened cloth placed between each series, are placed on each other, the power of the apparatus is materially increased.

The important discovery of accumulating the effects of this species of electricity was made by Volta in 1800, and thence has been denominated the Voltaic pile. The apparatus, as first made by Volta, consisted of a certain number of pairs of zinc and silver plates, separated from each other by pieces of wet cloth. Hence the arrangement was as follows: zinc, silver, wet cloth; zinc, silver, wet cloth, and so on. The silver plates were chiefly silver coins, the plates of zinc and the pieces of cloth being of the same size. He found this pile much more powerful when the pieces of cloth were moistened with a solution of common salt instead of pure water. A pile, consisting of forty pairs of plates, he found to possess the power of giving a very sharp shock, similar to that of a small electric jar; and that this effect took place as often as a communication was made between each end of the pile, and as long as the pieces of cloth remained moist.

To construct an apparatus of this kind, procure a number of plates of zinc and copper, or zinc and silver, either round or square, of any size; and an equal number of pieces of cloth, leather, or pasteboard, of the same form, but rather smaller. Soak these last in salt water, until they are thoroughly moistened; place a plate of silver, or copper, upon the table, then upon that place a piece of zinc, and on the zinc one of the moistened discs; upon this a second series of silver, zinc, and moistened cloth (or pasteboard) in the same order; and thus consecutively until a series of fifty or sixty repetitions have been arranged.

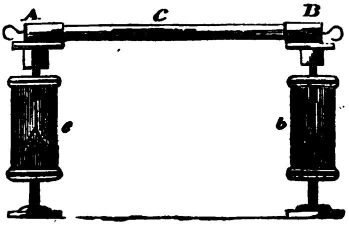
Particular care must be taken to place the plates in regular order; if in the first group silver is placed lowest, zinc next, and then the moistened disc, the same disposition must be observed throughout.

The Voltaic pile being thus formed, let the operator moisten both his hands with brine, and grasp a silver spoon in each. If the top of the pile be then touched with one spoon, and the bottom with the other, a distinct but slight shock will be felt at every repetition of the contact. This shock resembles very nearly the sensation produced by a very large electrical battery weakly charged; it is greater in proportion to the number of groups of which the pile is composed. If the communication is made with any part of the face near the eyes, or with a silver spoon held in the mouth, a vivid flash of light is perceived at the moment of contact, and that whether the eyes be open or shut.



A pile furnished with three rods to preserve the plates in a perpendicular direction, is shown in the accompanying diagram.

Another form of the pile must now be noticed. If a number of alternations be made of copper or silver-leaf, zinc-leaf, and thin paper, the electricity excited by the contact of the metals will be rendered evident to the common electrometer. C represents a glass tube, in which are regularly arranged a number of alternating plates of silver,



zinc, and thin paper, forming De Luc's electrical column. The metallic cap A is in contact with the silver plate, and B with the zinc plate, at the respective extremities of the pile. Upon examining the electrometers, it will be found that *c* is negatively diverged, and *b* positively.

To distinguish this instrument from the usual Voltaic apparatus, from which it differs in many respects, M. De Luc proposed to call it "the Electric Column," an appellation sufficiently appropriate, since the effects it produces are purely electrical.

Mr. Singer made very numerous experiments on the construction of such columns, and varied their combinations most extensively. The materials he preferred, are thin plates of flatted zinc alternated with writing or smooth cartridge paper, and silver-leaf. The silver-leaf is first laid on paper, so as to form silvered paper, which is afterwards cut into small round plates by means of a hollow punch. In the same way an equal number of plates are cut from thin flatted zinc, and from common writing or cartridge paper. These plates are then arranged in the order of zinc, paper, silvered paper with the silvered side upwards; zinc upon this silver, then paper, and again silvered paper, with the silver side upwards; and so on, the silver being in contact with zinc throughout, and each pair of zinc and silver plates separated by two discs of paper from the next pair. An extensive arrangement of this kind may be placed between three thin glass rods, covered with sealing-wax, and secured in a triangle, by being cemented at each end into three equidistant holes in a round piece of wood; or the plates may be introduced into a glass tube previously well dried, and having its ends covered with sealing-wax, and capped with brass; one of the brass caps may be cemented on before the plates are introduced into the tube, and the other afterwards; each cap should have a screw pass through its centre, which terminates in a hook outside. This screw serves to press the plates closer together, and to secure a perfect metallic contact with the extremities of the column.

There appears every reason to believe, that the action of a well-constructed column would be very durable. There is, however, a precaution necessary to their constant and immediate action; the two ends of a column should never be connected by a conducting substance for any length of time; for if, after such continued communication, it be applied to an electrometer, it will scarcely affect it for some time. It is, therefore, necessary, when a column is laid by, that it be placed upon two sticks of sealing-wax so as to keep its brass caps at the distance of about half an inch from the table, or other conducting surface on which it is laid. And if a column, which appears to have lost its action by laying by, be insulated in this way for a few days, it will usually recover its full power.

There is another cause of deterioration which is more fatal; it is the presence of too much moisture. If the paper be perfectly dry, it is a non-conductor, and will not therefore produce any action in the column; but this perfect dryness can only be obtained by exposing the paper to a heat nearly sufficient to scorch it, and in its dryest natural state the paper will be found sufficiently a conductor, even when, by exposing the paper discs to the heat of the sun, they have been so dried as to warp considerably. When the paper is sufficiently dry, the action of the column continues without diminution; and on taking such an apparatus to pieces after it had been constructed thirty months, no trace of oxidation was evident on the zinc plates.

Soon after the invention of the column, Mr. B. M. Forster discovered that, when a sufficiently extensive series was put together, its electric power was sufficient to produce a sort of chime by the motion of a small brass ball between two bells, insulated, and connected with the opposite extremities of the column. He constructed a series of 1500 groups, and by its agency kept a little bell-ringing apparatus in constant activity for a considerable length of time.

Mr. Singer contrived an arrangement which is well calculated to form a perpetual motion, by excluding, to a very considerable extent, the operation of extraneous causes of interruption, and it at the same time renders the disposition of the apparatus rather elegant. A series of from 1200 to 1600 groups are arranged in two columns of equal length, which are separately insulated in a vertical position by glass pillars constructed on his principle of insulation; the positive end of one column is placed lowest, and the negative end of the other; and, their upper extremities being connected by a wire, they may be considered as one continuous column. A small bell is situated between each extremity of the column, and its insulating support, and a brass ball is suspended by a thin thread of raw silk, so as to hang midway between the bells, and at a very small distance from each of them. For this purpose the bells are connected, during the adjustment of the pendulum, by a wire, that their attraction may not interfere with it; and, when this wire is removed, the motion of the pendulum commences. The apparatus is placed upon a circular mahogany base, in which a groove is turned to receive the lower edge of a glass shade with which the whole is covered.

There is some cause, not yet perfectly developed, that appears to influence the power of the column to produce the motion of light metallic pendula. In the bell-ringing apparatus, for instance, though the motion always continues, it is much more rapid at one period than another, and the oscillations of the pendulum, though usually as uniform as that produced by mechanism, is on some occasions singularly wild and irregular. The frequency with which the gold leaves of an electrometer strike the sides of the glass, when connected with an electric column, is also different at different times; the variations observed in some experiments of M. De Luc are much more considerable than we have yet noticed with the more powerful columns of Mr. Singer's construction.

It has been stated that the power of the moist galvanic pile gradually diminishes, the zinc surfaces becoming oxidated by the action of the moisture; it therefore requires to be taken to pieces and cleaned, an operation that is very troublesome when the number of plates is considerable. This inconvenience was diminished by soldering each pair of zinc and copper plates together, instead of simply laying them on each other; and a further improvement was devised by Mr. Cruickshanks, which consisted in cementing the pairs of plates in regular order, in grooves made in the side of a mahogany trough, so as to form water-tight cells between each pair. These cells being filled with water, or any conducting fluid, served as a substitute for the moistened discs used in the pile; and, as the fluid could be easily poured out and replaced, it required considerably less time to keep it in proper order. The form of the apparatus, which is called the Voltaic trough, or battery, has been much used in this country; it is perhaps, one of the best arrangements hitherto devised, and its construction is sufficiently simple.*

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* The plates need only be soldered together at their upper edges,

When the trough is prepared, the kind of fluid with which it is to be filled, must next be considered. Distilled

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because the other edges are secured by the cement. At the soldered edge, the copper is doubled over the zinc, in a degree equal to the thickness of the latter, and the solder is then applied with more ease, as a groove to contain it may be left between the two metals.

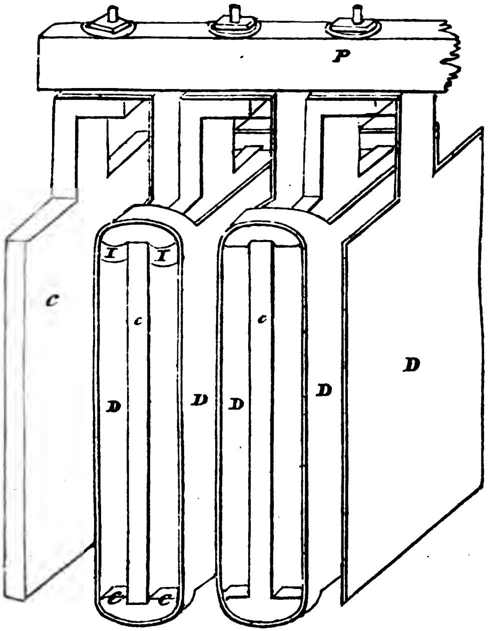
The plates should not be quite equal to the depth of the trough, for the convenience of filling; as when they do not reach the top, by leaning the trough on one side, each cell will receive an equal quantity of fluid.

The trough must have as many grooves in its sides as the number of plates it is intended to contain, which should be fewer in proportion to their size, otherwise the apparatus will be inconvenient from its weight. When the plates are not more than three inches square, their number in one trough may be fifty, and the distance of the grooves from three-eighths to half an inch. The trough must be made of very dry wood, and put together with white lead or cement. The plates being placed to the fire, the trough is to be well warmed, and placed horizontally on a level table, with its bottom downwards, very hot cement is then to be poured into it, until the bottom is covered to the depth of a quarter of an inch. During this process the plates will have become warm, and they are then to be quickly slided into the grooves and pushed firmly to the bottom, so as to bed themselves securely in the cement. In this way the plates are very perfectly cemented at the bottom, and, when this cement is sufficiently cool, a slip of thin deal is to be slightly nailed on the top edge of one of the sides of the trough, so as to overhang the inner surface about a quarter of an inch. The trough being about three quarters of an inch deeper than the diameter of the plates, there will be an interval between their top edges and the deal slip; and, when the side of the trough to which the slip is attached is laid flat upon the table, this interval forms a channel into which very hot cement is to be poured, and it will flow between each pair of plates, so as to cement one side of all the cells perfectly. As soon as the channel is quite full of fluid cement, the strip of deal is to be torn off, and the trough inclined so as to admit the superfluous cement to run out. When this is effected, and the cement cool, a slip of deal is to be nailed on the opposite side and the same process pursued with that. The instrument will then be cemented in the most perfect manner, and it may be cleaned off and varnished.

water will produce but a very slight effect, and it has been found that the power of the trough is greatly increased by the use of liquids which are capable of oxidizing, or exerting a chemical action on at least one of the metals; the water is therefore acidulated,—or some common salt, as muriate of ammonia. The series of fluids best calculated for this purpose will, however, be best understood by reference to a tabular view.

Positive Metal.	Negative Metal.	Interposed fluid.	Effect produced.
Zinc.	Platina.	Dilute sulphuric acid.	10
Ditto.	Gold.	Ditto.	10
Ditto.	Silver.	Ditto.	10
Ditto.	Palladium.	Ditto.	10
Ditto.	Copper.	Ditto.	8
Ditto.	Iron.	Ditto.	7
Iron.	Platina.	Ditto.	3
Ditto.	Ditto.	Dilute nitric acid.	3
Ditto.	Copper.	Dilute sulphuric acid.	0
Tin.	Platina.	Ditto.	4
Ditto.	Copper.	Ditto.	0
Ditto.	Iron.	Solution of caustic potash.	1
Ditto.	Copper.	Ditto.	½
Ditto.	Platina.	Ditto.	2
Zinc.	Ditto.	Ditto.	3
Ditto.	Copper.	Ditto.	2
Ditto.	Antimony	Dilute sulphuric acid.	2
Ditto.	Bismuth.	Ditto.	4
Ditto.	Platina.	Nitric acid.	10
Ditto.	Copper.	Ditto.	8
Tin.	Platina.	Ditto.	3
Copper	Ditto.	Ditto.	1
Silver.	Ditto.	Ditto.	¼

When different degrees of chemical action are excited in the Voltaic apparatus, by the introduction of various fluids, the more powerful the action that is produced the more transient is its duration. This circumstance is of importance in the practical application of the instrument, since it offers the means of judiciously applying various methods of experiments, and of continuing the action of the apparatus during any required time. When the battery is charged with water, its chemical action is feeble, but it appears to continue without diminution for an indefinite length of time; by the addition of a minute quantity of muriatic acid, 1-500th part for instance, its chemical action is greatly augmented, and still continues for a considerable period. When the proportion of acid is increased to a thirtieth or twentieth part, the action is considerable, but comparatively of short duration. Mr. Singer says, he has found no solutions so advantageous as those of acids, and he prefers the muriatic acid to all others; the nitric is indeed rather more powerful in the same proportion, but its cost is four times as great, and it is found that it destroys the copper plates as well as the zinc. The nitrous gas evolved by its action is also much more offensive than hydrogen, which results from the employment of muriatic acid.



Dr. Wollaston's arrangement of the plates materially increases the power of the apparatus. It consists in extending the copper plate, so as to oppose it to every surface of the zinc, as seen in the previous page. P is the rod of wood to which the plates are screwed; *c c* the zinc plates connected as usual with the copper plates D D, which are doubled over the zinc plates, and opposed to them upon all sides, contact of the surfaces being prevented by pieces of wood or cork placed at I I C C.

The Wedgwood ware battery is now generally employed when an extended series of plates are put into operation. These troughs contain compartments about half an inch broad, and they are about the same depth and length as the plates of ordinary troughs. Single plates of zinc and copper are united by a metallic arch at the top, so that they are parallel to each other, and at such a distance that the two plates can be placed in two adjoining compartments. When the battery is completed, each compartment is filled with fluid, and contains a plate of copper and a plate of zinc. This apparatus, in fact, combines the principle of the battery with glasses, and that of the common trough. As both surfaces of the metals are exposed to the action of the fluid, plates of the same size as those of the common trough expose twice the surface to oxidation; the galvanic effect is not, however, duplicated, although rather greater than with a single surface. The principal advantage consists in the facility with which the battery can be constructed, and the plates cleaned after having been used: it also admits of another adjustment, which is occasionally convenient; the plates are sometimes all united by a bar along the top of them; and they may then be raised or lowered by a rack work at pleasure, so that the charge can be reduced in any required proportion, and again increased to its full quantity.*

Mr. Pepys has contrived a single coil of copper and zinc plate, consisting of two sheets of the metals, each fifty feet long, by two feet broad, having, therefore, a surface of two hundred square feet; they are wound round a wooden centre, and kept apart by hair lines, interposed at intervals between the plates. This voltaic coil is suspended by a rope, and counterpoised over a tub of dilute acid, into which it is plunged when used.

It gives not the slightest electrical indications to the electrometer; indeed, its electricity is of such low intensity, that well-burned charcoal acts as an insulator to it; nor does the quantity of electricity appear considerable, for it with difficulty ignites one inch of platinum wire of 1-30th of an inch diameter. When, however, the poles are connected by a copper wire 1-8th of an inch diameter, and eight inches long, it becomes hot, and is rendered most powerfully magnetic, and the instrument is admirably adapted for all electro-magnetic experiments.

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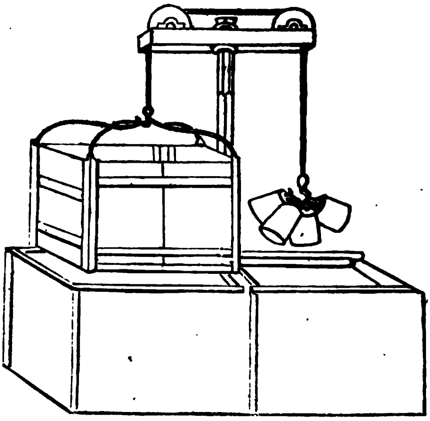
* Dr. Hare states, that having had occasion to remark the surprising increase in the deflagrating power of a series of galvanic pairs, when, after due repose, they were simultaneously exposed to the acid; he was induced to devise means of accomplishing this object in various ways, and that ultimately the following method occurred to him as the best: two troughs are joined lengthwise edge to edge so that when the sides of the one are vertical, those of the other are horizontal. Then by a partial revolution of the two troughs, thus united upon pivots which support them at the ends, any fluid which may be in one trough must flow into the other, and on reversing the motion, must flow back again. The galvanic series being placed in one of the troughs, the acid in the other, by a movement such as above described, the plates may all be instantaneously subjected to the acid, or relieved from it.

The pivots are made of iron, coated with brass or copper, as less liable to oxidizement; they are connected within with the galvanic series, and move on pieces of sheet-copper, which are easily made the extremities of connecting pieces, and thus the whole can be arranged in any way that is found convenient.

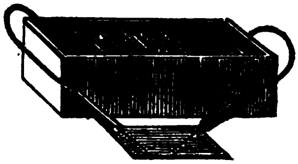
A modification of this apparatus will be seen in the accompanying diagram.



When the opposite extremities of a powerful Voltaic apparatus are connected by a wire, at the moment of contact a distinct spark is perceived, which occurs every time the contact is alternately broken and renewed. If the contact is made with a wire terminated at the end by a piece of well-burnt charcoal, the spark is considerably more vivid. And if the two wires proceeding from the opposite ends of the battery are armed with charcoal points, and brought in contact with each other, the light evolved is more brilliant and intense than any that has been procured by other artificial arrangements. When the battery is powerful, the emission of light may be kept up for a considerable time; it is so dazzling as to fatigue the eye even by a temporary glance, and, when it ceases, leaves the most brilliantly illuminated room in apparent darkness.

This light appears to be principally derived from the immediate action of the Voltaic apparatus, and not from the combustion of the charcoal; for, though that is partly ignited, it suffers but comparatively little waste, and the light is evolved with equal splendour when the experiment is made in gases which contain no oxygen; and will even take place, though with diminished energy, under water, alcohol, ether, oils, and other fluids whose conducting power is not too great.

The arrangement of the apparatus by which this is effected, is shown in the accompanying trough, with its wires and non-conducting plate to fire inflammable bodies.



With the most powerful Voltaic batteries the striking distance of the spark, or interval at which it passes from one conductor to another, is very considerable. Mr. Children measured this effect by means of a micrometer, attached to two polished points of platina, which were inserted in a receiver containing very dry air. With 1250 pairs of plates the points were brought within one-fifteenth of an inch of each other before the spark took place. With a large apparatus employed at the London Institution, which extends to 2000 pairs of four-inch plates, points of charcoal were brought within a thirtieth or fortieth of an inch of each other before any light was evolved; but, when the points of charcoal had become intensely ignited, a stream of light continued to play between them when they were gradually withdrawn, even to the distance of nearly four inches. The stream of light was in the form of an arch, broad in the middle and tapering towards the charcoal points; it was accompanied by intense heat, and immediately ignited any substance introduced into it; fragments of diamond, and points of plumbago disappeared, and seemed to evaporate, even when the experiment was made in an exhausted receiver; though they did not appear to have been fused. Thick platina wire melted rapidly, and fell in large globules; the sapphire, quartz, magnesia, and lime, were distinctly fused.

These phenomena may be exhibited on a smaller scale by means of 100 pairs of plates, of six inches square, an apparatus which is well suited for all experiments of fusion and ignition.

The arched form of the stream of light, passing between two charcoal points, is often very perceptible when the distance of the points does not exceed half an inch.

As the charcoal points usually become ignited when the battery has moderate power, almost any combustible substance may be inflamed, if placed between them. Oils, alcohol, ether, and naptha, are decomposed when the points are plunged into them, and inflamed when they are brought near each other upon the surface.

Some of the most pleasing effects of the Voltaic apparatus result from its action on metals; if these substances, in thin leaves, are made the medium of communication between the opposite ends of a powerful battery, they inflame, and by continuing the contact may be made to burn with great brilliance. The best method of performing these experiments, is to suspend the metallic leaves to a bent wire proceeding from one extremity of the battery, and to bring in contact with them a broad metal plate connected with the opposite extremity; the brilliancy of the effect may be increased by covering the plate with gilt foil. Gold-leaf burns with a vivid white light tinged with blue, and produces a dark brown oxide. Silver-leaf emits a brilliant emerald green light, and leaves an oxide of a dark grey colour. Copper produces a bluish-white light attended by red sparks; its oxide is dark brown. Tin exhibits nearly similar phenomena, its oxide is of a lighter colour. Lead burns with a beautiful purple light; and zinc with a brilliant white light, inclining to blue, and fringed with red. For the distinct appearance of these colours it is essential to make the contacts with the metal; for, if charcoal be used, the brilliant white light it evolves absorbs the colours produced by the combustion of the metals.

If a fine iron wire be connected with one extremity of a powerful battery, and its end be brought to touch the surface of some quicksilver connected with the other extremity, a vivid combustion both of the wire and the quicksilver results, and a very brilliant effect is produced.

If a fine iron wire of moderate length be made the medium of connexion between the extremities of the battery, it becomes ignited, and may be fused into balls; or if a platina wire is employed, it may be kept at a red, or even white, heat, for a considerable length of time; which seems to prove that some power is continually circulating through it; but however powerful the battery, wires are never dispersed by it, as they are by the action of a charged surface.

If a slender wire be inserted in any fluid, and then introduced into the Voltaic circuit, the fluid may be made to boil.

The contact of either surface of the battery with the ground increases the electrical state of the opposite extremity, and as experiment proves this to be the case, the same circumstance may be presumed to take place with every pair of associated metals, when their surfaces are in contact with a conducting fluid. Whilst the apparatus is insulated, the first zinc plate can only act on the electricity of its associate, the first copper plate; but the second zinc plate, through the conducting interposed fluid, can act on both these, besides its companion, the copper, and may therefore become more highly positive; and it is easy to conceive that such a repetition of action would be attended with an increase of effect, proportioned to the number of plates; and that the electrical tension of either end must be increased by connecting the other with the ground.

To ascertain if this principle really operated with a single combination, Mr. Singer took a pair of circular plates of six inches diameter, very clean and smooth, one being formed of zinc and the other of copper, and each provided with an insulating handle. When both plates were held by their insulating handles, and the zinc was successively applied to the flat surface of the copper, and after each contact made to touch the insulated plate of a condenser of six inches diameter; twenty contacts were required to communicate such a charge to the condenser as would occasion the leaves of a very delicate electrometer to separate to a quarter of an inch. But when the copper plate, instead of being held by its insulating handle, was simply laid on the hand, or on any similar conducting body, ten successive contacts of the insulated zinc plate, communicated a charge to the condenser, which occasioned the gold leaves to separate to the distance of more than half an inch. On repeating these experiments, with the variation of touching the condenser with the copper plate, held by its insulating handle, and brought in contact with the zinc plate, first insulated, and then uninsulated, similar results were obtained, but with the contrary electrical state. Hence the similarity of action in a single pair of metals, and a combined series, is sufficiently proved; and the preceding statement of the manner in which the electrical power is supposed to increase with the number of associated plates, is rendered highly probable.

The first experiments made upon the moist pile in this country appear to have been performed by Messrs. Nicholson and Carlisle. After observing the effects then ascribed to the piles on bringing the wires from each end of the column in contact with a drop of water, they observed a disengagement of bubbles of some elastic fluid.

On closer examination they found the gas to be hydrogen. They then took a glass tube, about half an inch in diameter, into each end of which a cork was inserted, the tube being filled with water, Through each cork was introduced a brass wire, so that the ends of the wires in the glass were about an inch and three-quarters of an inch. The pile employed consisted of thirty-six half-crowns, and as many similar pieces of zinc, and wet pasteboard. The zinc end of the pile was then connected with one of the wires in the tube, and the silver end with the other, so that the circuit formed by the pile was separated by the water in the tube placed between them. A stream of bubbles was observed at the end of the wire, in the tube connected with the silver end of the pile, No gas was disengaged from the opposite wire, but it speedily became tarnished, first of an orange colour, and ultimately black. The tube was then reversed, when it was observed that the wire, which in the first experiment became tarnished, gave out bubbles, while that which had before given out gas, in its turn became tarnished.

The emission of gas from the wire connected with the silver end of the pile was constant and uniform, except when a metallic circuit was formed between the ends of the pile, during which no gas whatever appeared. It was observed that, when this metallic conductor was removed, the appearance of the gas was not immediate, since there was an interval of about two seconds between the removal of the wire and the appearance of bubbles. After the process had continued two hours and a half, a bulk of gas was produced equal to two-thirds of a cubic inch. This gas was mixed with an equal bulk of common air, and exploded on the application of a lighted taper.

These ingenious experimenters, supposing the phenomena in question to arise from the decomposition of the water, thought it surprising that the hydrogen should make its appearance at a distance of an inch and three quarters from the point where the oxygen was disposed of. They then made the same experiment with a tube thirty-six inches in length, but no gas was observed. When they introduced an infusion of litmus instead of pure water, they observed that the fluid in the vicinity of the wire connected with the zinc end of the pile became red, and hence were led to suppose that an acid had been produced. The fluid at the other wire was not changed, but gas, as usual, was evolved.

In Sir H. Davy's Bakerian lecture on the chemical agencies of electricity, published in the Philosophical Transactions for 1807, he amply proved that acids, which are electrically negative, with respect to alkalies, metals, and earths, are separated from these bodies in the Voltaic circuit at the positive pole; and that alkalies, metals, and earths, are separated from acids, at the negative surface. He showed further, that such are the attracting powers of these surfaces, that acids are transferred through alkaline solutions, and alkalies through acid solutions, to the poles where they have their points of repose. This was exhibited by making a combination of three agate cups, one containing sulphate of potash, one weak nitric acid, and the third distilled water. The three were connected by asbestos moistened in pure water, in such a manner, that the surface of the acid was lower than the surface of the fluid in the other two cups. When two wires of platina from a powerful Voltaic apparatus, are introduced into the two extreme cups, the solution of the salt being positively electrified, a decomposition took place, and in a short time, a portion of potash was found dissolved in the cup, in contact with the negative wire, though the fluid in the middle cup was still sensibly acid.

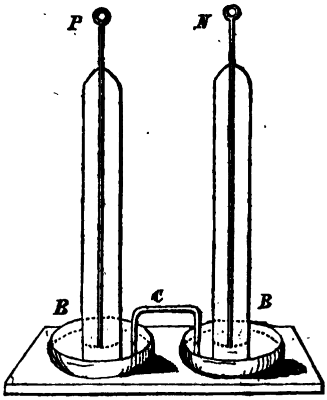
As the current of electricity excited by the Voltaic apparatus, acts on the bodies through which it passes, and often attacks and decomposes them; it must also, by the same power, act upon all the decomposible bodies which enter into the construction of its own system; so that it becomes indispensable to examine, by experiment, the nature, the extent, and the consequences of this action.

Among the phenomena which it produces, the first to be examined, because it is the most general, is a rapid absorption of the oxygen of the air around the apparatus. This may be rendered apparent in a very simple manner, by placing a vertical pile upon a support surrounded with water, and covering it with a cylindrical jar of glass, which also dips into the water at its base. In a few instants, the water will be seen to rise in the interior of the jar, especially if we form the communication between the two poles of the pile by metal wires, so as to direct through them the circulation of the electricity: when no communication is formed, the absorption still goes on, but with much greater slowness. In every case, in more or less time, according to the volume of the pile, and the quantity of air which surrounds it, the absorption ceases, and the air remaining under the jar presents no more traces of oxygen.

When we separate the elements of the piles which have been thus kept in action during several hours, or even days, under a cover which prevents the renewal of the atmospheric air, and having a constant communication kept up between their poles, we find that the metallic plates which compose them adhere to each other, and to the intermediate moistened cloths, with so great a force, that it is difficult to separate them. When this is done, we observe that the chemical action of the pile appears to have reacted on it, and produced remarkable alterations in its own elements. If the pile has been raised, according to the order, zinc, moisture, copper, zinc, and placed on its zinc base, we observe invariably that particles detached from the inferior zinc plate have been carried to, and have fixed themselves on the plate of copper above it, while particles of copper have been transported to the superior zinc, and so on from the bottom to the top of the columns. If the situation of the pile is the reverse, namely, copper, moisture, zinc, copper, the copper descends upon the zinc, which is below it, and the zinc on the copper, from the bottom to the top of the column. The direction of the passage through the pile is reversed, but it remains the same relatively to the order of the elements of which the apparatus is composed.

According to this arrangement, the zinc, in order to reach the copper, must necessarily pass through the small piece of moistened cloth which separates them. In piles where the communication between the two poles is not formed, this transmission does not sensibly take place; the surface of the copper remains smooth, and that of the zinc, which is opposite to it, is only covered with minute black lines, which follow the direction of the threads of the cloth. When the communication has been established for a short time, some particles of oxide begin to pass, and attach themselves to the copper; and, if the action of the pile is strong, the surface of the copper is at last entirely covered; then the chemical and physiological action of the pile ceases, either because the oxide of zinc deposited on the copper exerts on it an electromotive action, which balances that of the metallic zinc, touching it on its other side; or because the interposition of this stratum of oxide presents too great an obstacle to the transmission of the electricity; or lastly, what is most probable, because these two effects combine their influence at the same time.

A beautiful illustration of the effects resulting from electrical transfer may readily be adduced.



Fill the glass tubes represented in the above diagram, which are closed at top and open at bottom, with infusion of violets, or red cabbage, and invert them in the basins B B, containing a solution of Glauber's salt, and connected by the glass tube C, also containing the blue infusion. P and N are platinum wires, which pass into the tubes nearly to the bottom, and which are to be connected with the positive and negative extremities of the Voltaic apparatus. It will be found that oxygen is evolved at the wire P, and hydrogen at N, derived from the decomposition of the water. The Glauber's salt, which consists of sulphuric acid and soda, will also be decomposed, and the blue liquor will be rendered red in the positive vessel, by the accumulation of sulphuric acid, and green in the negative, by the soda, while the acid and alkali will each traverse the tube C without uniting, in consequence of being under the influence of electrical attraction.

Procure four glass tubes, one-fourth of an inch internal diameter, and about four inches long, bent in the form of the letter U. Fill these tubes with blue cabbage liquor, the interrupted metallic circuit being formed through them by connecting arcs of platina wire. When the extremities of this apparatus are connected with the opposite wires of a Voltaic battery, after a short time, the liquor in that leg of each syphon which inclines towards the copper extremity of the battery will become green, and that in the opposite leg red; and by reversing the connections, those legs which were green, may be rendered red, and those that were red converted to green.

That these phenomena depend on the transmission of electricity, from metal to water, and from water to metal, is demonstrated by the following variation of the experiment.

Remove all the platina wires but the two end ones, and connect the four syphons (filled with blue test liquor as before) by three arcs of moistened cotton. When the end wires have been some time connected with the opposite ends of the battery, the liquor in the two syphons next the copper side will be wholly changed to green, and that in the two syphons next the zinc extremity will be wholly changed to red. Hence it is probable, that when the electric fluid passes from metal to water, it separates oxygen, or acid; and when it passes from water to metal, it separates hydrogen, alkali, or inflammable matter.

The most difficult feature of all the Voltaic decompositions, is the invisible form in which the separated elements of various compounds appear to traverse the fluid, and arrange themselves at the opposite wires. The oxygen and hydrogen that appear in some of our experiments, at the distance of three feet from each other, are necessarily supposed to result from the same particle of water; and if this be situated at either wire, one of its elements (either the oxygen or hydrogen) must pass through the whole length of the tube to reach the other, and that in an invisible state, for the gases are separated at the opposite extremities without any apparent alteration of the interposed fluid.

Let the wires of a galvanic battery be made to terminate in a flat-bottomed vessel, containing pure water, about an inch and a half from each other; if then another wire, of an inch in length, be laid longitudinally between them, but not to touch them, each end of the intermediate wire, if of gold or platina, will afford gas. That end opposite the negative wire will give oxygen, and the other end of the same will furnish hydrogen; and if any number of bits of wire be placed between the principal wires, at the same time they do not touch each other, oxygen and hydrogen will be alternately furnished by the ends of the wires.

When the principal wires are brought nearer together, and a platina wire placed transversely between them, one side of the intermediate wire will furnish oxygen, and the other hydrogen. This fact is put in a more striking point of view, by placing a plate of platina in a vessel of water edgeways, and bringing the wires of the battery opposite to each other, and perpendicular to the sides of the plate. If the battery employed consist of fifty plates, three inches square, a circular spot will be observed on each side the plate opposite the wires. This appearance is caused by the evolution of gas from those parts of the plate only.

If a plate of glass be coated over with a solution of nitrate of silver, and a brass pin or a piece of zinc wire be laid in the middle of the plate, beautiful ramifications of silver will soon appear as if growing out of the pin; very much resembling vegetation. By observing the process with a magnifying glass, each branch of this arborescence may be seen to grow from the end or side of another; which proves that the silver forming the vegetative appearance is not reduced by the oxydable metal laid on the plate, but by something at the successive points of the silver branches. With a view to ascertain this fact, one half of the plate may be covered with nitrate of silver, and the other half with dilute muriatic acid. If a piece of zinc wire be tied to a piece of platina wire, and the compound wire so bent that the zinc may touch the dilute acid, and the platina the nitrate of silver, the ramifications of silver will soon appear upon the platina wire. That the silver is reduced by the hydrogen carried in the galvanic current, is probable, from varying the experiment as follows: if, instead of coating the plate with nitrate of silver, the whole be covered with dilute acid, and the same compound arc be laid upon it, the platina will give out bubbles of hydrogen. In the common way of making this experiment with the pin, as well as the variation above stated, it appears that the process is kept up by the galvanic current, which furnishes the hydrogen. The pin first reduces a small portion of silver, which forms a galvanic combination with the pin. The hydrogen which, but for the presence of the remaining nitrate of silver, would appear in the gaseous form, is employed in depriving the silver of its oxygen. With the compound arc, the zinc does not require to touch the nitrate of silver, because the platina with zinc is already a galvanic combination. The theory of whitening common pins can be explained on this principle. The tin, in a small proportion, is dissolved in the tartrate of potash; pieces of metallic tin, with the pins, are also present. The two latter form the galvanic combination, and a portion of tin is reduced from the solution upon the pins, to which they owe their whiteness.

The phenomena that have been described as the consequences of Voltaic decomposition obtain in every variety of experiment. Sulphuric acid introduced into the Voltaic circuit gives off oxygen gas, and sulphur is deposited. Phosphoric acid evolves oxygen gas, and phosphorus combines with the negative wire. Ammonia separates into hydrogen and nitrogen with a small proportion of oxygen. Oils, alcohol, and ether, when acted on by a powerful battery deposit charcoal, and give off hydrogen. And Professor Brande has shown, that when animal fluids containing albumen, are placed in the Voltaic circuit, the albumen is separated in combination with alkali at the negative wire, and in combination with acid at the positive wire. And that, with a powerful battery, it separates at the negative wire in the solid form; and with a less power, in the fluid form, so that it is probable animal secretion may depend on some such power.

The decomposition of the alkalies may, by care and attention, be effected with a battery of fifty pairs of plates of three or four inches square; but the results are rather uncertain: two hundred plates form a very efficient arrangement; they should be excited by a weak acid mixture (about one part strong muriatic or nitrous acid, to thirty parts of water). A plate of silver or platina being connected with the negative side of the battery, a thin piece of pure potash or soda is to be placed upon it, and a platina or silver conductor, proceeding from the positive side of the battery, is to be brought in contact with the upper surface of the alkali, which soon fuses at the points of contact: metallic globules shortly appear near the negative surface, and gradually increase in size, until a crust of alkali begins to form on their surface; at this moment they should be removed by the point of a knife, and instantly plunged under naptha; or, if the experiment be merely intended to demonstrate their production, they may be brought in contact with the surface of water or nitric acid. It sometimes happens that no globules appear, but if the contact be preserved for some time, and the alkali be afterwards raised, several will be found imbedded in its under surface. If the action of the battery be strong, it also sometimes happens that the globules inflame, and even detonate at the moment of their production; it is therefore advisable not to bring the eyes too near during the experiment, or else to cover them with glasses. These experiments always require great care to insure their success, which a trifling variation in the power of the battery, purity of the potash, or moisture of the atmosphere, may prevent.—Soda is rather more difficult to decompose than potash, and therefore requires to be employed in thinner pieces; the pieces of potash should rarely exceed a quarter of an inch in thickness, and those of soda one-eighth of an inch.

To prevent the loss of the alkaline bases during their separation, by the powerful action of the air upon them, it has been proposed to effect the decomposition under naptha: the moist potassa being placed between two plates of platina in a proper vessel, which is to be filled with naptha as soon as the contact with the battery is established; in this way the action of the air is prevented, but the naptha decomposes, and hydrogen and charcoal are liberated, which renders the result less satisfactory than in the more simple form of the experiment. The most essential precautions are to preserve the alkali as dry as is consistent with a sufficient degree of conducting power, and to employ the battery in a moderate state of action, in which it does not produce a very intense heat, for that would destroy the metallic base at the moment of its production.

The amalgam of potassium, or sodium, with mercury, is easily procured; and may be obtained by a very moderate power. A glass tube, one-fourth of an inch diameter and three inches long, having a short platina wire sealed in one end, is to have mercury poured into it until the end of the platina wire is covered; the rest of the tube is to be filled with a concentrated solution of alkali, either pure or carbonated. The platina wire, surrounded by mercury, is then to be connected with the negative end of a Voltaic battery, and the circuit completed by bringing a platina wire from the positive end, in contact with the solution of alkali. Gas will be evolved from this wire, and the surface of the mercury will be greatly agitated; when the action grows weaker, the mercury may be poured into a glass of water, and the presence of the alkaline metal will be immediately indicated by the evolution of a cloud of minute bubbles of hydrogen gas, which may be collected by inverting over the mercury a small closed glass tube filled with water. This result has been frequently obtained with a battery of thirty pairs of plates of only two inches square. The amalgam may be obtained more highly charged with the alkaline metal by employing a solid piece of alkali, with a small cavity on its surface, in which a globule of mercury is to be placed. The alkali is to be connected with the zinc surface of a battery, and the mercury with the copper surface; the mercury soon becomes more tenacious, and sometimes is converted into a soft solid mass, and in this state, if thrown into water, it produces a rapid decomposition.

Mr. Hare has observed, that the charcoal points, when ignited by the instrument, " assumed a pasty consistence, and appeared as if in a state of fusion." This most important fact seems to have been placed beyond a doubt by Professor Silliman, who has obtained some very curious and valuable results with a powerful galvanic apparatus. When the charcoal points were brought into contact, and then withdrawn a little, the most intense ignition took place. The charcoal part of the positive pole shot out and increased from the tenth to the eighth, and sometimes to the fourth of an inch in length. The charcoal of the negative pole, on the contrary, was diminished, and a circle-shaped cavity was formed at the end of it, as if the matter had been actually transferred to the positive pole, by a current flowing from the negative to the positive pole. From various experiments Professor Silliman concludes, " that there is a current from the negative to the positive pole, and carbon is actually transferred by it in that direction," probably in the state of vapour.

Upon examining with a microscope the projecting point of the positive pole, it exhibited decisive indications of having undergone a real fusion. It presented a mamillated appearance, and its form was that of an aggregation of small spheres. Its surface was smooth and glossy, as if covered with a varnish. Its lustre was metallic, and it had entirely lost the fibrous appearance it previously possessed.

The power possessed by certain animals of destroying the electrical equilibrium, and of rendering this apparent by the transmission of shocks to other bodies, is too important to be passed without notice.

In the *gymnotus* or *electric eel*, and in the *torpedo* or *electric ray*, are arrangements given to those remarkable animals for the purposes of defence, which nearly resemble Voltaic apparatus, for they consist of many alternations of different substances. These electrical organs are much more abundantly supplied with nerves than any other part of the animal, and the too frequent use of them is succeeded by debility and death. We may, however, notice them somewhat more in detail.

The *torpedo*, which belongs to the order of *rays*, is a flat fish, very seldom twenty inches in length, weighing but a few pounds when full grown, and commonly caught in various parts of the sea-coast of Europe. The electric organs of this animal are two in number, and placed one on each side of the cranium and gills, reaching from thence to the semicircular cartilages of each great fin, and extending longitudinally from the anterior extremity of the animal to the transverse cartilage which divides the thorax from the abdomen. In those places they fill up the whole thickness of the animal from the lower to the upper surface, and are covered by the common skin of the body, under which, however, are two thin membranes or fasciæ. The length of each organ is somewhat less than one-third part of the length of the whole animal. Each organ consists of perpendicular columns, reaching from the under to the upper surface of the body, and varying in length according to the various thickness of the fish in various parts. The number of those columns is not constant, being not only different in different torpedos, but likewise in different ages of the animal, new ones seeming to be produced as the animal grows. In a very large torpedo, one electric organ was found to consist of 1182 columns. The greatest number of those columns are either irregular hexagons, or irregular pentagons, but their figure is far from being constant. Their diameters are generally one-fifth part of an inch. "Their coats are very thin, and seem transparent, closely connected with each other, having a kind of loose net-work of tendinous fibres passing transversely and obliquely between the columns, and uniting them more firmly together: these are mostly observable where the large trunks of the nerves pass. The columns are also attached by strong inelastic fibres, passing directly from the one to the other."

Each column is divided by horizontal partitions, placed over each other at very small distances, and forming numerous interstices, which appear to contain a fluid. These partitions consist of a very thin membrane, considerably transparent. Their edges appear to be attached to one another, and the whole is attached by a fine cellular membrane to the inside of the columns.

The above-mentioned electric organs seem to be the only parts employed to produce the shock; the rest of the animal appearing to be only the conductor of that shock, as parts adjacent to the electric organs; and, in fact, by artificial electricity, it has been found that the animal is a conductor of the electric fluid. The two great lateral fins which bound the electric organ laterally, are the best conductors.

The *gymnotus electricus* has been frequently called the *electric eel,* on account of its superficial resemblance to the common eel; though, when accurately examined, it is found to have few of the specific properties of that animal. The gymnotus is found pretty frequently in the great rivers of South America.

M. Humboldt, in his " Personal Narrative," furnishes a very interesting account of the mode of catching the gymnoti, which inhabit some of the rivers and pools of South America. M. H. would not employ the roots of the Piscidea erithryna and Jacquinia armillaris, which, when thrown into the pool, would intoxicate or benumb the animals; as these means would have enfeebled them: the Indians therefore said they would fish with horses, and the guides were soon seen returning from the savannah, which they had been scouring for wild horses and mules. They brought about thirty with them, which they forced to enter the pool. The extraordinary noise caused by the horses' hoofs, made the fish issue from the mud, and excited them to combat. The yellow and livid eels, which resembled large aquatic serpents, swam on the surface of the water, and crowded under the bellies of the horses and mules.

This singular contest between animals so different in their organization, appears to have furnished a very striking spectacle. The Indians, provided with harpoons and long slender reeds, surrounded the pool closely, while others climbed the trees which hung over its banks, and by their wild cries prevented the horses from running away. The eels, stunned by the noise, attempted to defend themselves by the repeated discharge of their electric batteries, and for a time appeared victorious, as several horses sunk beneath the violence of the invisible strokes; while others, panting, with mane erect, and haggard eyes, raised themselves and endeavoured to fly from the storm by which they were overtaken. But few, however, succeeded in gaining the shore, and these stumbling at every step, stretched themselves on the sand, exhausted with fatigue, and their limbs benumbed by the electric shocks of the gymnoti.

In less than five minutes the *humane* conductors of this exhibition had succeeded in drowning two horses, and M. Humboldt imagined that the fishing would terminate by killing successively all the animals engaged; but by degrees, the impetuosity of this unequal combat diminished, and the wearied gymnoti dispersed. On the fish approaching the edge of the marsh, they were readily taken by means of a small harpoon, and when the cord to which the instrument was attached was free from moisture, the Indians felt no shock in raising the fish from the water. The temperature of the pool was about 86° of Fahrenheit, and the electric energy of the fish was supposed to diminish in colder water.

Some of the gymnoti measured by M. Humboldt exceeded five feet in length, and the Indians asserted that they had seen them still longer. The transverse diameter of the body was more than three inches, and a fish of three feet ten inches in length weighed twelve pounds.

The gymnoti of Cano de Bera are of a fine olive-green colour; the under part of the head being yellow mingled with red. Two rows of small yellow spots are placed symmetrically along the back, from the head to the end of the tail; each of which contains an excretory aperture, so that the skin of the animal is constantly covered with a mucous matter, which it appears conducts electricity more than twenty times as well as pure water.

We may now notice some of the electric effects which resulted from a variety of experiments with these fish. First shocks from large and strongly irritated gymnoti were as much as possible avoided; and if by chance a stroke was received, the pain and numbness was so violent as to exceed all description. M. H. says he never received so severe a shock from common electricity as he experienced from having incautiously placed both his feet on the body of a fish just taken from the water, and he adds that he was afflicted for the rest of the day by a violent pain in almost every joint. The gymnotus, when in a state of extreme weakness, merely causes a twitching sensation, which is propagated from the part that rests on the electric organs, as far as the elbow, every stroke producing an internal vibration, that lasted two or three seconds, and accompanied by a painful numbness. The electric action of the fish appeared to depend entirely on its will, each shock being accompanied by a depression of the eyes.

The electric organ of the gymnoti acts only under the immediate influence of the brain and heart, for on cutting a very vigorous fish through the middle of the body, the fore part alone gave shocks; but these in a live fish are equally strong in every part of the body. Resinous substances, glass, very dry wood, horn, and even bones prevent the action of the gymnoti from being transmitted to man, but M. Bonpland received shocks when carrying an eel on two cords formed of the fibres of the palm-tree.

Although it has been seen that the shock from this fish is at least as powerful as any that can be produced by artificial electricity; and the electric spark has even been elicited by Messrs. Walsh and Ingenhousz, yet in no case has it exhibited the phenomena of attraction or repulsion, both of which can be produced by the Voltaic pile.

The third fish which is known to have the power of giving the shock, is found in the rivers of Africa, but we have a very imperfect account of its properties. This animal belongs to the order which the naturalists call *silurus;* hence it is commonly called *silurus electricus.* Some of those fishes have been seen even above twenty inches long.

The body of the silurus electricus is oblong, smooth, and without scales; being rather large, and flattened towards its anterior part. The eyes are of a middle size, and are covered by the skin which envelopes the whole head; each jaw is armed with a great number of small teeth. About the mouth it has six filamentous appendices. The colour of the body is greyish, and towards the tail it has some blackish spots.

The electric organ seems to be towards the tail, where the skin is thicker than on the rest of the body, and a whitish fibrous substance, which is probably the electric organ, has been distinguished under it.

It is said that the silurus electricus has the property of giving a shock or benumbing sensation like the torpedo, and that this shock is communicated through substances that are conductors of electricity; but no other particular about it is known with any considerable degree of certainty.

For a knowledge of the *medical* use of the galvanic agency, we are mainly indebted to Professors Galvani and Aldini, on the Continent, and Dr. Wilson Philip, in England. Numerous experiments made on dead animals, as well as on human subjects, had previously proved, that galvanism had a peculiar effect on the nervous and muscular system, and led to the conclusion, that this singular agent must possess some sanative as well as energetic influence on the actions of diseased living beings, and would effect cures or afford relief in nervous disorders. This supposition was verified by several trials, and numerous instances have, subsequently, confirmed its efficacy in those disorders, as well as in many other complaints. Galvanism has not only been used to cure the afflicted living, but also to resuscitate the apparently dead; and in suspended animation it has been found to be a test of vitality, and the surest criterion of recent death. Dr. Grapengiesser, of Berlin, one of the principal writers on medical galvanism, who strongly recommends its use in palsies, rheumatism, debility of sight, nervous deafness, hoarseness, white swellings of the joints, tumours in the glands of the neck, &c. concludes by observing, that galvanism not only possesses a stimulating power over the nerves and muscles, but also over the vital forces; and that it moreover possesses resolutive and derivative qualities. M. Sprenger, of Jenna, an able administrator of galvanism, gives an account of his having restored the sense of hearing to forty-five persons, to four of whom he also restored the sense of smelling. Dr. Wilkinson, in his "Elements of Galvanism," has related a variety of cases in which it was applied with the greatest advantage by Continental practitioners; and he also describes the beneficial effects which were produced by its use under his own immediate direction in paralytic and spasmodic affections.

Experience has proved that the medical effect of electricity is not confined to the Voltaic apparatus, but that the ordinary electrical machine may be made most effective in producing sanative effects. The auxiliary apparatus requisite for medical purposes are the following:—A jar fitted up with Lane's electrometer, by which shocks may be given of any required force. A pair of directors, each consisting of a glass handle, surmounted by a brass cap with a wire of a few inches in length, having a ball screwed on its extremity, which may be occasionally unscrewed and a wooden point substituted for it.

When shocks are given by means of these directors, they must be applied at the opposite extremities of the part through which the charge is required to pass; and being respectively connected by conducting wires, the one with the outside of the jar, and the other with the receiving ball of the electrometer previously placed at the requisite distance, the jar may be set to the machine, which is then put in motion until any required number of shocks has been given.

The insulated director is also employed to give sparks, being held by its glass handle, and its ball previously connected with the conductor by a fine chain being brought near the patient, or rubbed lightly over a piece of flannel or woollen cloth laid on the affected part. When the eye or any delicate organ is electrified, the ball of the insulated director is unscrewed and the wooden point applied, at the distance of about half an inch from the part. The stream of electricity which passes from the point, in such cases, produces rather a pleasant sensation than otherwise.

An insulated stool is sometimes employed; it should be of sufficient size to receive a chair upon it, with a resting-place in front of the chair for the feet. The patient being placed on the insulated chair, and connected with the conductor of the machine by means of a chain, sparks may be drawn from any part of the body by a person who stands on the ground and presents a brass ball to it.

MAGNETISM.

Nature of Ferruginous Bodies.—Loadstone.—Artificial Magnets.—Magnetising Power of the Prismatic Spectrum.—Magnetism applied to Nautical Purposes.—Construction of the Compass.—Attempted Insulation.—Barlow's Apparatus.—Dipping Needle.

THIS science may justly be considered as yet but in its infancy, although the facts elicited since the commencement of the nineteenth century, by Barlow, Morichini, and Davy, bid fair to throw considerable light on some of its more recondite principles.

The theory of magnetism bears a very strong resemblance to that of electricity, and it must therefore be placed near it in a system of natural philosophy. We have seen the electric fluid not only exerting attractions and repulsions, and causing a peculiar distribution of neighbouring portions of a fluid similar to itself, but also excited in one body, and transferred to another, in such a manner as to be perceptible to the senses, or at least to cause sensible effects, in its passage. The attraction and repulsion, and the peculiar distribution of the neighbouring fluid, are found in the phenomena of magnetism; but we do not perceive any actual excitation, or perceptible transfer of the magnetic fluid from one body to another; and it has also this striking peculiarity, that metallic iron is very nearly the only substance capable of exhibiting any strong indications of its presence.

The most simple experimental illustration of the effects of magnetic attraction may be thus illustrated. If the north pole of a magnetised bar be presented to a similar pole of another bar, it will be repelled, or driven away from it; but if, on the contrary, two opposite poles be presented towards each other, they will be attracted.

From this it will be seen, that a north pole always repels a north pole, and attracts a south pole. And in a neutral piece of soft iron, near to the north pole of a magnet, the fluid becomes so distributed by induction, as to form a temporary south pole next to the magnet, and the whole piece is of course attracted, from the greater proximity of the attracting pole. If the bar is sufficiently soft, and not too long, the remoter end becomes a north pole, and the whole bar a perfect temporary magnet. But when the bar is of hard steel, the state of induction is imperfect, from the resistance opposed to the motion of the fluid; hence the attraction is less powerful, and an opposite pole is formed at a certain distance within the bar; and beyond this another pole, similar to the first; the alternation being sometimes repeated more than once. The distribution of the fluid within the magnet is also affected by the neighbourhood of a piece of soft iron, the north pole becoming more powerful by the vicinity of the new south pole, and the south pole being consequently strengthened in a certain degree; so that the attractive power of the whole magnet is increased by the proximity of the iron. A weak magnet is capable of receiving a temporary induction of a contrary magnetism from the action of a more powerful one, its north pole becoming a south pole on the approach of a stronger north pole; but the original south pole still retains its situation at the opposite end, and restores the magnet nearly to its original condition, after the removal of the disturbing cause.

To explain the phenomena of magnetism, Æpinus suggested the following hypothesis. He imagined that there must exist a fluid capable of producing all the phenomena of attraction and repulsion, and with a subtilty so great, as to penetrate the pores of all bodies; and also of an elastic nature, its particles being repulsive of each other. At the same time he imagined a mutual attraction between the magnetic fluid and iron, or other ferruginous bodies. According to this hypothesis, iron and all ferruginous substances contain a quantity of magnetic fluid, which is equally dispersed through their substance, when those bodies are not magnetic; in which state they show no attraction or repulsion towards each other, because the repulsion between the particles of the magnetic fluid is balanced by the attraction between the matter of those bodies and the said fluid, in which case, those bodies are said to be in a natural state; but, when in a ferruginous body, the quantity of magnetic fluid belonging to it is driven to one end, then the body becomes magnetic, one extremity of it being now overcharged with magnetism, and the other extremity undercharged. Bodies thus modified, or rendered magnetic, exert a repulsion between their overcharged extremities, in virtue of the repulsion between the particles of that excess of magnetic fluid, which is more than overbalanced by the attraction of their matter. There is an attraction exerted between the overcharged extremity of one magnetic body, and the undercharged extremity of the other, on account of the attraction between that fluid and the matter of the body; but to explain the repulsion which takes place between their undercharged extremities, we must either imagine that the matter of ferruginous bodies, deprived of its magnetic fluid, must be repulsive of its own particles, or that the undercharged extremities appear to repel each other, only because either of them attracts the opposite overcharged extremities; both which suppositions are embarrassed with difficulties. A ferruginous body, therefore, is rendered magnetic by having the equable diffusion of magnetic fluid throughout its substance disturbed, so as to have an overplus of it in one or more parts, and a deficiency of it in the remainder, and it remains magnetic as long as its impermeability prevents the restoration of the balance between the overcharged and undercharged parts.

The distinction between conductors and non-conductors is with respect to the electric fluid, irregular and intricate: but in magnetism, the softness or hardness of a ferruginous body constitutes the main distinction. And it is well known that magnetic effects are produced by quantities of iron, incapable of being detected either by their weight or the most delicate chemical tests. M. Cavallo found that a few particles of steel, adhering to a hone, on which the point of a needle was slightly rubbed, imparted to it magnetic properties; and M. Coulomb has observed that there are scarcely any bodies in nature which do not exhibit some marks of being subjected to the influence of magnetism, although its force is always proportional to the quantity of iron which they contain, as far as that quantity can be ascertained. Dr. Young considers a single grain sufficient to make twenty pounds of another metal sensibly magnetic.

The *loadstone*, or natural magnet, is a heavy iron ore, and is found in large masses in every quarter of the globe.*

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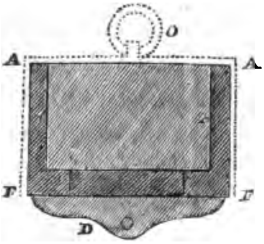
* The loadstone was originally called *lapis Heracleus*, from Heraclea, a city of Magnesia, a part of the ancient Lydia; where it is said to have been first found, and from which it is usually supposed to have

Three very large loadstones have lately been brought from Moscow to this country, and an account of them read before the Wernerian Society, by Mr. Deuchar. The largest of these natural magnets weighs more than 125lbs., and measures in length 10¾ inches, in breadth 8½, and in height 9½ inches. When first examined, it supported 163lbs.; but, by gradually increasing the weight, it was afterwards brought to support 165lbs., exclusive of a connecting iron and supports of 40lbs. The weight of the second loadstone had not been taken previous to fitting on the armature, but it was supposed to be nearly half that of the large one, and it supported above 80lbs. These natural magnets were brought to this country in the same vessel, and it appeared probable that the corresponding poles had been placed together, as those of the weakest had been reversed.

A mode of protecting and increasing the power of natural magnets is sometimes resorted to—they are then said to be *armed.*



A A represents a magnet thus contrived, and A F the armature or pieces of iron, the projections for which are at F F, and to which the central piece of iron D, is made to

taken its name; though others derive the word from a shepherd named Magnes, who discovered it by the iron of his crook on Mount Ida.

adhere. The dotted line represents a brass box, having a ring O, at its upper part, by which the armed magnet may be suspended. Thus the two poles of the magnet which are at F and F, are made to act on every part alike, and the straight piece of iron D, may be conveniently applied for supporting a weight.

There are some important circumstances which require attention, in order to enable us to ascertain the best method of constructing artificial magnets.

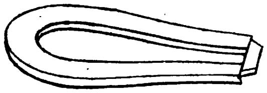
The nature of the body must be adapted to the power which is to render it magnetic; remembering, that soft ferruginous bodies both acquire and lose magnetism more easily than those which are harder.

Several magnets are much preferable to a single one, for the purpose of communicating magnetism; in the application of which it must be remembered that the south pole of the magnet produces a north pole in the part of the ferruginous body to which it is first applied, while the north pole of the magnet produces a south pole.

If it were required to construct a strong magnet, when the operator has either no magnet at all, or a very weak one, he must proceed gradually. It being impossible for a hard and large steel bar to receive any sensible degree of magnetism from the action of the earth, or of any other weak magnet; the operator must begin with giving magnetism to several small and soft steel bars, impregnating one at a time by means of the weak magnet, or, if he have no magnet, by means of one or more iron rods properly situated, which in that case are real, though weak magnets. Then, by joining in a proper manner the small steel bars already made magnetic, he may communicate a stronger power to larger and harder steel bars.

Mr. Michell's method of making magnets may be thus described: prepare a dozen bars of steel, of about 1¾ ounce weight each, six inches long, and half an inch broad: let these be hardened by immersion into water at a red heat. The size and shape of the bars may be varied at pleasure, provided that the length be proportioned to the thickness. The best sort of steel is that which has no veins of iron in it, and Mr. Michell found the common blistered steel at least equal to any other. In order to preserve the bars, they must be placed in a box furnished with two pieces of iron, about an inch long each. These pieces of iron may be about a quarter of an inch square, and should be filed perfectly smooth on the sides. Against these are to be placed, with their edges towards them, the twelve magnetical bars, six on one side, with their south, or north poles one way, and six on the other side, with the same poles the contrary way. It is necessary to observe that these bars must neither be taken out, nor put in, all, or too many on a side at once; for if two only be left, with their poles of the same denomination the same way, without one or more on the other side, to counterbalance their effects, they will injure each other. In order to make the marked ends of these bars south poles, and the other ends north poles, place six of them in a line north and south, bringing the unmarked end of one, to touch the marked end of the next throughout; the marked ends lying towards the north, which will be some advantage to them. Then take an armed magnet, and placing it with both poles upon one of the bars, the north pole towards the marked end, which is to be a south pole, and the south pole towards the unmarked end, which is to be a north pole, slide it backwards and forwards from end to end of the whole line of bars three or four times, taking care that they all touch. Then taking it off, remove the two endmost bars into the middle, and pass over them again three or four times. Having thus touched the bars, it will not be improper to turn them with the other side uppermost, and to magnetise again on that side as before, omitting the endmost bars, till they are removed into the middle, when they must undergo the same process.

Professor Steinhauser has ascertained, that if by the process of Canton, we unite, in the form of a square, two steel bars, and two contacts of iron, it is better to operate by the double touch in a circle, than by a motion backwards and forwards. Again, when we combine these bars in a square, the force of that which we wish to magnetise, ought to increase in proportion as the other magnet has become more energetic. In magnetising horse-shoe magnets, it is much more advantageous to place two of these bent bars, with their friendly poles so situated, as that the magnetic circle be completed; and that we should then touch circularly, with the magnet destined to communicate the power. When the two horse-shoe bars are separated, they lose usually a considerable part of their force, if we do not previously decompose the great circuit into two smaller ones, by applying each contact to its curved magnet before the separation. In this way, the two separated magnets lose little or nothing of their power; and two may be touched in the same time that one is on the usual plan. By conforming to these rules, Professor Steinhauser has succeeded in making magnets of extraordinary power, in the least possible time.



Among artificial magnets, those which are bent into a form resembling the diagram on the preceding page, so that the two ends nearly meet, and therefore called horse-shoe magnets, are reckoned the most powerful. To render such a shaped piece magnetic, place a pair of magnetised bars against the ends of the horse-shoe, with the south end of the bar against that of the horse-shoe which is intended to be north, and the north end of the bar to that which is to be the south; the lifter, of soft iron, to be placed at the other end of the bars. Also rub the surfaces of the horse-shoe with the pair of bars disposed like the legs of compasses when a little open, or with another horse-shoe magnet, turning the poles properly to those of the proposed magnet; and being careful that these bars never touch the ends of the straight bars. To prevent a sudden separation of the bars from the horse-shoe, which would considerably diminish the force of the latter, slide on the lifter, or support, to the end of the horse-shoe magnet, but in such a manner that it may not touch the bars; they may then be taken away, and the support slid to its place.

The power of a magnet, and of iron or steel impregnated with the magnetic virtue, may be impaired by long lying in a wrong position, with regard to the earth or with respect to each other. Thus, if two magnets be placed so, that their contrary poles may be contiguous, they will preserve one another's power; but if the north pole of one be placed near the north pole of the other, and the south near the south, then they will entirely destroy, or diminish each other's magnetism; and if their original powers were very unequal, the polarity of the weaker magnet will be changed by the action of the stronger one.

In general, the same means which facilitate the communication of magnetism, when pieces of iron, &c. are properly situated with respect to the poles of the earth, or of other magnets, will likewise facilitate the loss of magnetism, when the magnets are improperly situated; thus, a red heat destroys in a great measure, or entirely, the power of a magnet. A steel bar, strongly magnetic, will have its power much diminished by being repeatedly struck between two stones, especially if it be struck standing in a direction perpendicular to the magnetic meridian. A bar of hard iron, which has acquired some degree of permanent magnetism, by being made red-hot, and then cooled in the direction of the magnetical line, will have that power destroyed, or much diminished, by a few blows on its middle.[*]

The directive power of a magnet is extended to a greater distance than its attractive power; for instance, if a magnet be freely suspended, another magnet properly situated within a certain distance of the former, will turn it out of its ordinary direction; yet the degree of attraction exerted by these magnets against each other, is not sensible at that distance; which may be easily tried, by fixing one of the magnets to the scale of a balance. The reason of this property is, that the directive power depends both upon the attraction of the poles of different names, and on the repulsion of those of the same name; whereas the attraction takes place only between poles of different names. In order to render this view of the matter more intelligible, we may imagine a magnetic needle freely suspended, and placed within the influence, or sphere of action of a magnet. In this disposition, suppose that the north pole of a magnet attracts the south pole of a magnetic needle with a force equal to ten grains, and, as the attraction between poles of different names is nearly equal to the repulsion between poles of the same name, it follows, that the same north pole of the magnet repels the north pole of the magnetic needle with a force equal to ten grains: but these two forces both concur in altering the direction of the needle; therefore, the endeavour of the magnet to turn the needle's direction is equal to twenty grains; whereas the attraction, or the force by which the needle is drawn towards the magnet, is only equal to the difference between the two above-mentioned opposite forces, which difference arises from the pole of the magnet being nearer to one than to the other of the poles of the needle. The same reasoning may be applied to the action between the south pole of the magnet and the suspended needle.

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[*] Some have imagined that iron or steel might be rendered heavier or lighter by magnetism. Whiston says that he found, by accurate experiments with large needles, that after the touch they weighed less than before. One of 4584½ grains lost 2⅝ grains by the touch; and another of 65,726 grains, lost no less than 14 grains. It appears, however, tolerably evident, that the vicinity of iron, or of some other ferruginous body, must have produced the change.

Mr. Scoresby has invented a very useful piece of apparatus called a *magnetimeter*. This instrument consists of a small table of brass, about 4 inches square, and 3 inches high, having a plate of brass attached to it by hinges, and moveable by means of a wheel and pinion, through an arc of 250° of a vertical circle. This plate has a small straight groove running from end to end, for the purpose of receiving bars of metal, the polarity of which is to be determined. These bars are readily fixed to the plate, by being slipped through a circular aperture in the end of a spring, which, perforating the moveable plate, is marked by a graduated circle, screwed on the side of the table. On the brass table is placed a moveable flat plate of brass, divided into degrees, and furnished with a magnetic needle with an agate cap traversing on a brass or steel point. The needle can be changed according to the nature of the circumstances; a very light and strongly magnetised one being used in delicate experiments. The compass, or plate carrying the needle, being moveable, its distance from the bar resting on the moveable plate, can be varied at pleasure. The centre of the hinge is one-tenth of an inch above the level of the table; and the bars in use, being one-fourth of an inch in diameter, are sunk in the groove of the moveable plate to such a depth, that their axis, or centre, precisely corresponds with the centre of the hinges; hence the middle of the extremity of each bar is at the same elevation, and at the same distance from the needle in every position of the moveable limb. To give firmness to the instrument in making experiments, the table is fixed by the feet to a mass of lead, of seven or eight pounds weight. By means of this plate of lead, which has a screw at each corner, the whole apparatus is readily put into a horizontal position. With this apparatus, Mr. Scoresby made a series of experiments, which are fully detailed in the Transactions of the Royal Society of Edinburgh, vol. 9th, and of which the following are the principal results.

1. Iron bars become magnetical by position, except when placed in the plane of the magnetic equator; the upper end, as regards the position of the magnetic equator, becoming a south pole, and the lower extremity a north pole.

2. No attraction or repulsion appears between a magnetised needle and iron bars; the latter being free from permanent magnetism, whenever the iron is in the plane of the magnetic equator; consequently, by measuring the angle of non-attraction, in a bar placed north and south, we discover the magnetic dip.

3. Before a magnet can attract iron, that is totally free from both permanent magnetism and that of opposition, it

infuses into the iron a magnetism of contrary polarity to that of the attracting pole.

4. A bar of soft iron, held in any position, except in the plane of the magnetic equator, may be rendered magnetical by a blow with a hammer, or other hard substance; in such cases, the magnetism of position seems to be fixed in it, so as to give it a permanent polarity.

5. An iron bar, with permanent polarity, when placed any where in the plane of the magnetic equator, may be deprived of its magnetism by a blow.

6. Iron is rendered magnetical if scoured or filed, bent or twisted, when in the position of the magnetic axis, or near this position; the upper end becoming a south pole, and the lower end a north pole; but the magnetism is destroyed by the same means, if the bar be held in the plane of the magnetic equator.

7. Iron heated to redness, and quenched in water, in a vertical position, becomes magnetic; the upper end gaining south polarity, and the lower end north.

8. Hot iron receives more magnetism of position than the same when cold.

9. A bar-magnet, if hammered when in a vertical position, or in the position of the magnetic axis, has its power increased, if the south pole be upward, and loses some of its magnetism if the north end be upward.

10. A bar of soft steel, without magnetic virtue, has its magnetism of position fixed in it, by hammering it when in a vertical position; and loses its magnetism by being struck when in the plane of the magnetic equator.

11. An electrical discharge, made to pass through a bar of iron, devoid of magnetism, when nearly in the position of the magnetic axis, renders the bar magnetic; the upper

end becoming a south pole, and the lower end a north pole; but the discharge does not produce any polarity if the iron be placed in the plane of the magnetic equator. The effects appear to be the same, whether the discharge be made on the lower or upper end of the bar, or whether it be passed longitudinally or transversely through the iron.

The action of light on ferruginous bodies is, under peculiar circumstances, capable of producing magnetism.

Morichini and Cosimo Ridolfi, two ingenious Italian philosophers, were the first to call public attention to the fact, for they found that small steel needles acquired magnetism, by being placed in the violet ray of a spectrum, produced by the decomposition of white light. Mrs. Somerville has, however, gone further than the Continental philosophers, for she proved that the magnetising power was not confined to the one coloured ray, but that nearly the whole series were capable of producing this singular effect.

The application of magnetism to *nautical* purposes must now be noticed. The history of the compass is involved in much obscurity, as the Chinese appear to have possessed

this important instrument long prior to its use in Europe. The apparatus consists of a moveable magnet or needle, usually supported on a steel point, which occupies the axis of a cylindrical case, called the compass box, as is shown in the preceding page. For this purpose, there is formed in the needle itself, a cap or hollow conical centre of brass, or agate, on which it rests, and to this is attached the compass card. The tendency of the needle to be disturbed by agitation, will greatly depend upon the position of the vertex of the conical cavity. It is necessary that it should be above the centre of gravity; but this distance must be so small, as that the libration of the needle when one end is depressed, should be very slow, and yet speedy enough to recover the horizontal position. In fact, the whole of the steadiness of the compass and its box appears to depend on the principle of slow vibration. For, if a needle perform its vertical vibration in eight seconds, it will be very little disturbed by an alternate action that lasts but a second or two.

It is commonly imagined that the agitation of the compass is communicated by friction at the points or edges of suspension, and the compass-maker has accordingly exerted his ingenuity to diminish this friction, by contrivances similar to that of a conical cap balanced on a point, and itself affording another point to support the needle. But it may be readily proved by experiment, that the greatest disturbance of the needle is produced by the quantity of horizontal progressive motion, and not by the mere inclination or angular motion. A compass-needle supported on a simple point, will suffer very little agitation from any angular motion, or moderate deviation from perpendicularity in the pin; but it will instantly begin to vibrate if moved horizontally. Thus the common experiment of tilting the compass-box in all positions, while its centre remains immoveable, is fallacious.

It appears, therefore, that the steadiness of a needle which vibrates slowly, is the consequence not only of the length of time it allows for alternate actions to operate, and destroy each other; but also of the difficulty with which it yields to such impressions. If the centres of suspension and of gravity in the needle were coincident, no angular motion would be produced by any action of the pin, excepting by the effects of friction; and the angular motion produced in other cases will be less, the shorter the distance between these two centres, or the lever by which it is propagated.

The simple suspension of the needle on a point, has been applied to the compass-box, for which it is little suited, not only because of the wear upon so small a surface, but also because it admits the box to traverse horizontally; an effect, which is inconvenient, and cannot be remedied by any means not calculated in some respect to increase the effects of agitation. The method most generally employed, and in fact, the one best adapted to the purpose, consists in employing gimbals.

This well-known contrivance consists of a hoop supported upon two pins diametrically opposite each other, and issuing from the external surface of the ring in such a direction that both lie in the same diameter line. When the hoop is suspended on these pins, it is at liberty to turn freely round the diameter of which they constitute the prolongation. The notches or holes of support are disposed horizontally. The compass-box itself is placed in a similar ring, with two projecting pivots; and these pivots are inserted in holes made in the former ring at an equal distance from each of its pivots. If, therefore, we suppose the whole to be left at liberty, the compass-box may vibrate upon the diametral line of the outer ring, and also upon a line formed by its own pivots, at right angles to that diametral line. The consequence of this arrangement is, that the centre of gravity of the compass-box will dispose itself immediately beneath the intersection of both lines on which it is at liberty to move:—that is to say, if the weight of the box or its parts be properly disposed, the compass will assume a position in which its upper surface shall be horizontal.

The same principles which were applied to the single centre of the magnetic needle will also apply to the axis of the gimbals. If the centre of gravity of the compass-box be so placed with respect to either axis as that its vibrations shall be quick, every horizontal action will greatly disturb it, and it will not speedily settle. The most favourable position of the pivots or edges of support in the gimbals will be when they all lie in the same plane; and the centre of gravity of the compass-box is very little below that plane.*

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* The following valuable results relative to the best mode of constructing the compass-needle, form part of an admirable paper, by Captain Kater, inserted in the Transactions of the Royal Society. 1. That the best material for compass-needles is clock-spring; but care must be taken, in forming the needle, to expose it as seldom as possible to heat, otherwise its capability of receiving magnetism will be much diminished. 2. That the best form for a compass-needle is the pierced rhombus, in the proportion of about five inches in length to two inches in width, this form being susceptible of the greatest directive force. 3. That the best mode of tempering is, first to harden the needle at a red heat, and then to soften it from the middle to about an inch from each extremity, by exposing it to heat sufficient to cause the blue colour which arises, again to disappear. 4. That in the same plate of steel of the size of a few square inches only, portions are found varying considerably in their capability of receiving magnetism, though not apparently differing in any other respect.

The *azimuth compass* nearly resembles the instrument already described. The principal difference consists in the adaptation to it of two sights, through which the sun, or a star may be seen, to find its azimuth, and thence to ascertain the declination of the needle at the place of observation. These sights are upright pieces of brass, placed opposite each other; in one of them is an oblong aperture, with a thread or slender wire stretched down the middle of it: the other sight contains only a narrow slit, of the same length, consequently, the thread in the one sight is just opposite the space in the other, and the observer knows when he looks through them centrally. The ring of the gimbals rests with its pivots on a semicircle, the foot of which turns in a socket, so that, without moving its external box, the compass may be turned round, in order to place the sights in the direction of the sun, star, or other

5. That polishing the needle has no effect on its magnetism. 6. That the best mode of communicating magnetism to a needle, appears to be by placing it in the magnetic meridian, joining the opposite poles of a pair of bar magnets, (the magnets being in the same line,) and laying the magnets so joined, flat upon the needle, with their poles upon its centre; then having elevated the distant extremities of the magnets, so that they may form an angle of about two or three degrees with the needle, they are to be drawn from the centre of the needle to the extremities, carefully preserving the same inclination, and having joined the poles of the magnets at a distance from the needle, the operation is to be repeated ten or twelve times on each surface. 7. That in needles from five to eight inches in length, their weights being equal, the directive forces are nearly as the lengths. 8. That the directive force does not depend upon extent of surface, but, in needles of nearly the same length and form, is as the mass. 9. That the deviation of a compass-needle, occasioned by the attraction of soft iron, depends, as Mr. Barlow has advanced, on extent of surface, and is wholly independent of the mass, except a certain thickness of the iron, amounting to about two-tenths of an inch, which is requisite for the complete developement of its attractive energy.

object to be viewed. This instrument is used to take the bearings of headlands, ships, and other distant objects.

Lieutenant Littlewort has contrived a method, by which the ordinary hanging compass may be converted into an azimuth compass, so that merchant vessels may have the benefit of this important instrument, with which they are seldom supplied. The handle by which the compass is suspended to the roof of the cabin is capable of being inverted, and of supporting the compass, by sliding in a groove made in a box, which box is capable of motion on a central pin fixed in the board on which the box stands; moveable sights and a stop are also annexed, to enable it to act when required as an azimuth compass.*

Mr. Wales, who accompanied Captain Cook in his second voyage, appears to have been the first person who observed the effects of the iron employed in ship building, upon the action of the magnetic needle. This subject was further investigated by Captain Flinders, who, in his survey of the coast of New Holland, succeeded in applying a correction for the use of his own vessel.

From an account of the survey, published some time after this navigator's return, it appeared that in Captain Flinder's vessel, and, indeed, in every ship, a compass would differ very materially from itself, in being removed from the head to the stern. This was found to arise from the iron which surrounds the compass becoming magnetic, and its entire attractive force is thus concentrated into one powerful focus. Of this, the principal south pole is situated near the middle of the upper deck. This focus of attraction so influences the compass-needle, that it is subject to a considerable variation from the true meridian, different from what is observed by a compass on shore; the north point of the compass being constantly drawn towards the focus in our hemisphere, and the south point in the opposite hemisphere.

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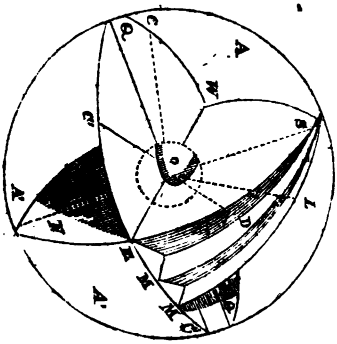
* A figure and description of this compass, will be found in the Transactions of the Society of Arts, vol. xi. p. 70.

With these facts in view, Professor Barlow commenced a series of experiments to remedy the defective apparatus. Having procured a solid iron ball, thirteen inches in diameter, he found, on placing the compass above it, that the north end of the needle was attracted by the upper part of the ball; that when placed below the ball, the south end was attracted; and that when the needle was raised or depressed in any vertical around the ball, it always passed through a point in which both attractions became neutralized. The next step in his investigation was to ascertain whether these points of no attraction were all in the same plane; and if so, to determine correctly its inclination to the horizon,—since it had become obvious from the care with which the trials had been made, that it was not parallel to it. This question was soon decided: by a series of experiments it was demonstrated that the points were all in the same plane, and that the inclination of the plane itself to the horizon was about 20°, declining directly from the magnetic north point to the south, approaching very nearly to the compliment of the dip of the needle. This circle, Mr. Barlow now traced on his iron ball, assuming as its principal axis the direction of the dipping needle; and, imagining circles of latitude and longitude to be described around the whole ball, he had thus an ideal magnetic sphere, which would readily indicate the relative position of the iron and the compass in his subsequent experiments. The annexed diagram on the following page, will enable the reader to form a correct idea of the nature and pro-



perties of this magnetic sphere. Here O is supposed to represent an iron ball, and A, A, A, a sphere circumscribing it, and within which its influence is active; S, N, being in the magnetic meridian. The line N S, in the plane S, E., N, W, denotes the natural direction of the dipping needle, in those latitudes where its inclination to the horizon is about 70½°. Now, conceiving Q, E, Q', W, to represent a plane, passing through the centre of the ball, and being perpendicular to the axis N S, it will be the *plane of no attraction*, which has this remarkable property, that if lines be drawn in it, (as for example, the lines O C, O, C', O C'', &c.) and a compass be placed any where in those lines, or indeed in any point of the plane Q, E, Q', W, it will be uninfluenced by the iron ball, and will preserve its natural magnetic direction.

As soon, however, as the compass is removed out of this plane, the needle is found to deviate from its original bearing—its south end being attracted towards the ball when the needle is below the plane, and its north end when it is above; and in every case the deviation follows a determinate law, so that the amount being given in any one case, it may be ascertained for all others.

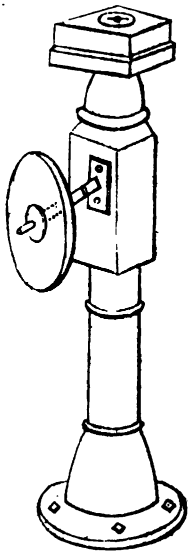
Suppose, for example, any two other planes, passing through the centre of the ball, each being perpendicular to Q, E, Q′, W, of which let M, O, S, L, represent quadrants; then supposing a compass placed in each of these planes, at equal distances from the centre, at L, we shall have M L, for the latitude, and E M, E M′, for the longitude of position of those points; then will the following proportion express the law in question: — The tangent of the deviation of the compass at L, is to the tangent of the deviation of the compass at L′, as the rectangle of the sine of 2 L M + cosine E M, to the rectangle of the sine of 2 L′ M′ + cosine of E M′, E, being the east point of the horizon.

Pursuing this inquiry, Mr. Barlow next ascertained by a series of experiments, the law of attraction at different distances of the compass from the iron ball; and which he thus states:—That while the position as to latitude and longitude is the same, *the tangents of the angles of deviation are reciprocally proportional to the cubes of the distances.*

Still, however, there remained an important question to be solved, viz.—When the position and distance are the same, what is the law of deviation as it respects the mass of the attracting body? And here a most unexpected result was obtained. From the first experiments, which were made with a solid iron ball of ten inches in diameter, it appeared, as Mr. Barlow seems to have anticipated, *that the tangents of the deviations are proportioned to the cubes of the diameters,* all other things being the same; but happening at this time to make trial of an iron wheel of the same diameter as the ball, but only three-fourths of its weight, he was not a little surprised to find the results in both cases the same. "In fact," he remarks, "it appeared *that the power of attraction resided wholly on the surface, and was independent of the mass.*"

Before it was discovered that the power of an attracting body resides in its surface, Mr. Barlow had anticipated a great impediment in the way of final success, arising from the mass of iron which he considered as necessary to produce the desired effect. It now, however, readily occurred to him that, as surface is the principal thing to be attended to, a light, globular shell of iron, or a simple circular plate of the same metal, would be amply sufficient for the purpose. A plate of this description was accordingly tried; it was fifteen inches in diameter, and weighed only 4lbs. 13oz. With this plate Mr. Barlow repeated the series of experiments that had been made with the ball, and had the satisfaction of finding that its power was far greater than would be requisite for doubling the effect of the guns of any vessel in the navy, although applied to the exterior of the binnacle, and fifteen inches distant from the pivot of the needle. The precise situation for this correcting plate is, of course, a matter of essential importance, and cannot be fixed on until the local attraction of the vessel has been ascertained. This is effected in the following manner:—The ship being so moored as to admit of her head being directed to each point of the compass successively, and there steadied whilst the bearing of as remote an object as can be found is taken, it will then be found that the bearings thus taken vary from each other, according to the attractive power of the vessel, sometimes as much as 28°, which difference is caused by the iron of the ship drawing the needle from its proper direction to the eastward with the ship's head east, and to the westward with the head to the west. It will also be found that two of the bearings taken at opposite points of the compass, nearly agree with each other, and the mean of these is to be taken as the true magnetic bearing of the object. By these points, also, will be indicated *the line of no attraction* in the vessel, which in general is found to be nearly fore and aft, and in this line the plate is ultimately to be placed. This being accomplished, a pedestal or compass-stand is then taken ashore, and by trying different situations for it, and turning it about till the same deviations are produced by the plate at each point, as had been observed in the vessel. But this process, which is very troublesome, is now rendered unnecessary, the end being much more readily accomplished by means of a printed table, which is given with the correcting plate; and which comprises a series of attractions obtained by the plate, including all possible limits for every class of vessels. Corresponding to each degree of local attraction are given two numbers, the one indicating the distance of the centre of the plate below the pivot of the needle, and the other its distance from the centre line of the pedestal, and at this depth and distance the plate must be fixed, either fore or aft the compass; if the former, the effect of the vessel will be exactly doubled—and if the latter, it will be neutralized. When the plate is applied in front, which is reckoned preferable in southern voyages, it is not a fixture, but is applied at pleasure; but when placed behind, as recommended in northern voyages, where the disturbance from local attraction is very considerable, it is fixed in its place during the voyage, and the needle is thus left free to obey the influence of the magnetic power of the earth only.

It now remains to give some account of the plate itself. The plate employed by Mr. Barlow in his experiments, as well as those which he sent out by Captains Parry and Sabine, consisted of two circular pieces of sheet iron, weighing about 3lbs. per square foot, screwed together in such a



manner as to combine any strong irregular power of one plate, with a corresponding weak part on the other, by which means a more uniform attraction is produced; he is, however, of opinion that a single plate of iron, weighing about 6lbs. per square foot, would answer the purpose equally well. In diameter the plate may vary from twelve to sixteen inches, according to the power of the vessel. When the plate is made double, there is a circular board of the same size inserted between the iron discs, for the purpose of increasing the thickness, without adding much to the weight. The two plates thus separated are found to be more powerful than either a single plate, or two plates in immediate contact. The plates are perforated in the centre, and through this opening is passed a brass socket with a broad head, and having an exterior screw and nut, by which the two iron plates, and the interposed plate of wood, are compressed together. The accompanying figure represents the brass pin, socket, plate, pedestal, and compass, combined, as in action on ship-board.

Mr. Barlow, in the prosecution of his magnetical experiments, discovered a curious property in ferruginous bodies, which deserves to be recorded. Mr. Barlow's first object appears to have been to determine the relative magnetic power of different kinds of iron and steel on the needle, and his results, as connected with this determination, are as follow:—viz.

Malleable iron	100	Shear-steel, soft	66
Cast-steel, soft	74	Ditto, hard	53
Blistered-steel, soft	67	Blistered-steel, hard	53
Cast-steel, hard	49	Cast-iron	84

—that the above numbers express the relative powers of these different metals in deflecting a magnetised needle from its natural direction. Seeing that the hardest iron and steel had the least power, Mr. Barlow was next desirous of ascertaining what this comparative power might be when heated in a furnace, and while each of the different specimens were thus rendered soft.

The results of these experiments are not so uniform as in the preceding. It is remarkable, however, that the malleable iron, which has by far the greatest power when cold, has the least of any when heated; and that the cast-iron, which is the least powerful when cold, is the strongest when hot; the increase of strength in the latter case being nearly as 3 to 1.

It was also observed, that between the white heat of the iron, (when every species of magnetic action disappears), and the blood-red heat, (when the power manifests itself strongly), there was an intermediate action, which attracted the needle the contrary way when cold, or at the blood-red heat; that is, if the iron and compass are so posited that the north end of the needle is attracted towards the iron when cold, the south end will be attracted when the iron is red-hot, and vice versa; but as the red changes to the darkest shades of blood-red, the usual power of the iron commences, and the needle is deflected the contrary way. Moreover, this negative attraction is least in those positions where the natural cold attraction is the greatest, and greatest where the latter is the least, and greatest of all in that position where the cold attraction is zero; that is, in the plane of no attraction, provided (of course) the needle is sufficiently near to the bar. The bars used in the experiments were twenty-five inches in length, one inch and a quarter square, inclined in the position of the dipping-needle; the distance varying from five to nine inches; but the nearer to the bar, the more obvious are the effects. In some of the experiments, the quantity of negative attraction exceeded 50°.

It appears from a curious paper, by Mr. Fisher, on the errors in longitude as determined by *chronometers* at sea, that a sudden alteration takes place in their rate when taken on ship-board, an effect which has been generally ascribed to the motion of the vessel. He ascribes the acelleration which takes place, to the "magnetic action exerted by the iron in the ship, on the inner rim of the balance, which is made of steel;" and in proof of this, he found that analogous effects took place in chronometers when under the influence of magnets placed in different positions with respect to their balances. "Upon the whole," says Mr. Fisher, "it appears that chronometers will be generally accelerated (particularly if their balances have received polarity by the too near approach of any thing magnetical) on ship-board. It appears probable, likewise, that the force of the balance-springs is affected in the same way, since it is well known that chronometers having gold balance springs, although more difficult to adjust, yet keep better rates at sea than others.*

If the magnetic poles always agreed with the astronomical poles of the globe, the compass-needle must of necessity point due north and south in every part of the earth. This however, is not the fact, as the needle is found to vary considerably, not only after the lapse of ages, but also at stated periods, within a few hours of its maximum in either direction. In other words, the magnetic meridian, and the real meridian, seldom coincide. The angle which they make is called the *angle of declination*, and this is said to be *east* or *west* according as the north pole of the needle is eastward or westward of the true meridian of the place.

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* Philosophical Transactions, 1820.

From the minuteness of the daily variation, and the extreme difficulty of measuring it, excepting with the nicest instruments, its laws, and consequently its cause, are still undiscovered. It occurred to Mr. Barlow, that this deviation might be increased, both in the horizontal and the dipping needle, to between three and four degrees, by reducing the directive power of the needle, by means of one or two magnets, so disposed, as to balance, at least in part, the terrestrial influence. Mr. Barlow used a delicate needle, eight inches and a half long; and, by means of two magnets, he kept the needle balanced in different directions of the compass; and in these different directions he observed the daily changes in its position. The following were the results for the horizontal needle.

When the N. end of the needle was directed to any point from the S. to N N W. its motion, during the forenoon, is towards the left hand, advancing, therefore, to some point between the N N W. and N. When the N. end is directed towards any point between the N. and S S E., it passes to the right hand, advancing to some point between the N. and N N W. Hence, there ought to be some direction between these limits: viz. between the N. and N N W., and the S. and S S E., in which the daily motion is zero, or at least a minimum. Mr. Barlow likewise concluded, that the daily change was not produced by a general deflection of the directive power of the earth, but by an increase and decrease of attraction of some point between the N. and N N W., or between the S. and S S E.

Having reduced the power of a dipping-needle nearly eight times, by two magnets placed in the line of the dip, Mr. Barlow observed, that it passed suddenly one half-quarter degree to another, more or less, so as to give a difference in the dip of one and a half in one day.

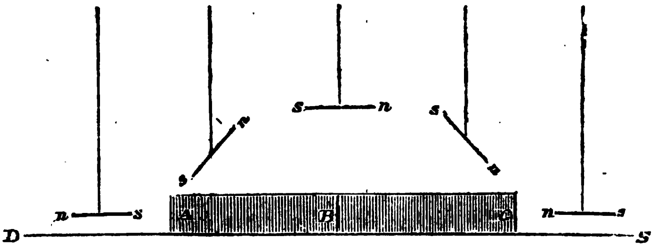
A memoir was presented to the French National Institute, by Humboldt and Biot, "On the Variations of the Terrestrial Magnetism in different Latitudes." These philosophers, having first determined the position of the magnetic equator by direct observations, proved that the magnetic force must increase in proceeding from that equator to the poles; and the same distinguished foreigners have given a mathematical hypothesis, which, when reduced to a formula, accords with all the inclinations of the needle hitherto observed.

As to the position of the magnetic equator, supposing it to be a great circle of the terrestrial sphere, an hypothesis which is conformable to observations: the inclination of this plane to the astronomical equator, is equal to 12·2025° of the decimal division, (10°58′56″ of the common division,) and its occidental node on that equator is at 133·3719° (120°2′5″) longitude west from Paris, that is, a little beyond the continent of America, near the Gallipagos, in the South Sea; the other node is at 66·6281° (59°57′55″) eastward of Paris, that is to say, in the Indian Seas. The points where the axis of the magnetic equator pierces the earth's surface, are, the northern point at 87.7975° (79°1′4″) of north latitude, and at 33°3719° (30°2′5″) of longitude west from Paris; the southern point is situated in the same latitude south, and 166·6281° (149°67′55″) of longitude east from Paris. It is remarkable that this determination of the magnetic equator agrees almost perfectly with that given half a century back, by Wilke and Lemonnier.

With respect to the intensity of the magnetic force in different parts of the earth, these philosophers have ascertained that it varies in different latitudes; its increase proceeding from the equator towards the poles. The needles of Humboldt's compass, which, at his departure, gave at Paris 245 oscillations in ten minutes, gave no more in Peru than 211, and it constantly varied in the same direction; that is to say, the number of the oscillations always decreased by approaching the magnetic equator, and always increased by advancing towards the north. The differences can neither be ascribed to a diminution of magnetic force in the compass, nor to the effects of heat or of time; for after three years residence in the warmest countries of the earth, the same compass gave again in Mexico, oscillations as rapid as at Paris.

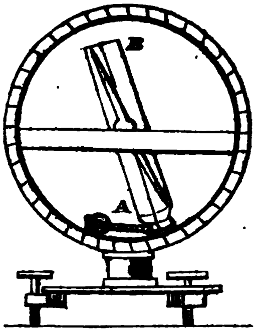
There are some anomalies, however, occasioned by local causes. Thus Biot having, in the summer of 1804, carried to the Alps the magnetic needle employed in one of his previous aerial excursions, he found that its tendency to return to the magnetic meridian was constantly stronger in these mountains than it was at Paris before his departure, and than it had been since his return. This needle, which made at Paris 83·9 oscillations in ten minutes of time, gave oscillations as below, at the places mentioned, in the same interval of ten minutes: viz. Paris, before departure, 83·9; Turin, 87·2; on Mount Genevre, 88·2; Grenoble, 87·4; Lyons, 87·3; Geneva, 86·5; Dijon, 84·5; Paris, after his return, 83·9. It appears to result from these observations, that the action of the Alps has a perceptible influence on the intensity of the magnetic force. Humboldt observed analogous effects at the bottom of the Pyrenees, for instance, at Perpignan. It is not improbable that they arose from the mass of these mountains, or the ferruginous matters contained in them ; but whatever may be the cause, it is hence manifest that the general action of terrestrial magnetism is sensibly modified by local circumstances, the differences of which may be perceived in places very little distant from each other.

If a common compass-needle be placed at the equator, it will be evident that the earth's attractive power must be equal at either pole, and, consequently, that the needle will remain in equilibrio. Should the compass needle be removed towards the north pole of the earth, the equilibrium will be immediately destroyed, and the south pole of the needle will then preponderate. It may hardly be necessary to add, that an effect exactly the reverse of this takes place when the needle is drawn towards the opposite pole.



The bar magnet A B C, will best explain the nature of this phenomenon, which is called the *dip* of the needle. The magnetized needle suspended over the equator B, is exactly parallel to the bar, and would be so to the plane of the earth's horizon ; but if we suppose the needle thus balanced to be placed over the north pole A, the south pole of the needle will dip towards it. Should we remove the needle still further, and place it exactly over the pole, it will arrange itself perpendicular to the plane of the horizon.

A reference to this simple experiment will serve to illustrate the construction and use of the *dipping needle* represented beneath. This instrument, though of late much improved, is still far from perfect. The general mode of constructing it is to pass an axis quite through the needle, whilst the pivots rest upon a bar crossing a large divided circle of brass. The stand is furnished with adjusting screws, by means of which it is readily placed in a perpendicular direction; but when used at sea, it is usually supported by a ring.



To observe the dip accurately in any particular situation, it is necessary, after having noted the angle formed on one side of the circle, to reverse the magnetism of the needle by the application of magnetic bars, so that the end of the needle which before was elevated above the horizon, may then be below it; on again observing the dip, a mean of the two observations will produce the most accurate result.

The dip of the needle was first observed by Norman in 1576, at which period, the north-pole of the dipping-needle, when placed in the neighbourhood of London, stood at 71°50' below the horizon; and in 1775, it was at 71°.3', the change in its angle during that period, being somewhat less than a quarter of a degree.

The phenomenon of the magnetic dip, or inclination of the needle, having been discovered by Norman, numerous theories were formed to account for such a wonderful phenomenon, and the latitude, on any meridian, was attempted to be discovered by its results; experience, however, very soon proved that its demonstrations were extremely erroneous; and it has since been adverted to more as a matter of scientific importance, than of real utility to navigation. Captain Flinders, in his last voyage of discovery, and M. Humbolt, in his valuable philosophical researches in the New World, have materially improved our acquaintance with the dipping needle, and have, in some measure, rendered its results valuable to the navigator. The former, at an early period of his voyage, observed that the indications of the dipping-needle had a close connexion with the change, occasioned by the local attraction of the ship, in the variation of the compass; and that, as the north or south end of the compass-needle was affected, so, in like manner, were the results of the dipping-needle increased or diminished: this affinity he considered as occasioned by the magnetism of the earth, and the attraction of the ship, acting upon the needle and forming a compound force; for when the north end of the needle had dipped, it was the north end of the compass-needle which was attracted by the iron-work in the ship; and that the errors produced by this combined attraction, were proportionate to the sines of the angles between the ship's head and the magnetic meridian. On the magnetic equator, where the dipping needle stands horizontally, or there is no dip, there seemed to be no local attraction; but after passing some distance into the southern hemisphere, when the south end of the needle had dipped, observations again showed errors in the compass-needle, but they were of a contrary nature to those experienced in the northern, which evidently proved that the south end of the compass-needle was now attracted. The importance of this discovery, deduced from many observations during the voyage, and verified after his return, by a series of observations made on board other ships, induced him to conclude that the error produced at any direction of the ship's head, would be to the error at east or west, at the same dip, as the sine of the angle between the ship's head and the magnetic meridian, was to the sine of eight points or radii.

From what we have already stated of the nature of the magnetic dip, it will be evident that the angle formed by the needle, must vary as the observer approaches to, or recedes from the poles, and that at the equator, it would assume a line parallel with the plane of the horizon. In the following table, Professor Hausteen has furnished us with a series of valuable observations upon this subject; they were made in 1819.

	Dip.		Dip.
Peru	0° 0′	Arendahl	72°45′
Mexico	42 10	Brassa	74 21
Paris	68 38	Hare Island	82 49
London	70 33	Davis's Straits	83 8
Christiana	72 30	Baffin's Bay	84 25

From a series of numerous and accurate experiments made by Captain Sabine, he obtained the following measures of the dip of the magnetic needle at London:—

By ten experiments with Tobias Mayer's needle . . .	70.2.9
By the times of oscillation in the magnetic meridian, and in the plane perpendicular to it. Mean by three needles .	70.4.0
By the times of vertical and horizontal oscillation . .	73.2.6
Mean . .	70.3.2

Hence Captain Sabine concludes, that 70°3′ was the mean dip of the needle at London, in August and September 1821, within a few hours of noon.

As the observations of Nairne and Cavendish give 70°25′ for the dip in 1774, we obtain 3.′02″ as the mean annual rate of diminution between 1774 and 1821.

Taking Mr. Whiston's determination of the dip in 1720, at 75°10′, which Mr. Cavendish considered as accurate, the annual diminution is 3′05″.

Having thus illustrated the nature of the magnetic dip, it may now be advisable to notice Biot's hypothesis, in which he attempts to determine the law which regulates the inclination of the needle in different parts of the globe. M. Biot supposes two centres of attraction, or northern and southern poles, situated at equal distances from the centre of the earth, and in the axis of the magnetic equator. He then calculated the effects which ought to result from the action of these centres upon any point of the earth's surface, assuming the attractive force in the reciprocal ratio of the squares of the distances; and the result was, that the nearer these assumed poles were brought to each other, the more perfectly did the calculation agree with experiment.

ELECTRO-MAGNETISM.

Magnetic Phenomena exhibited by the agency of Charged Electrical Surfaces.—Franklin's Experiments.—Effects produced by Van Marum and Von Buch.—Oersted's Discoveries.—Revolving Apparatus.—Thermo-electricity.

The intimate connexion that subsists between many of the phenomena described in the preceding section, with those observed in electricity, has given birth to a new science, which may be said to date its origin from the commencement of the present century. Amongst those who have done most towards the developement of *electro-magnetism*, we may especially enumerate M. Oersted, Sir Humphry Davy, and Professor Barlow, and the latter of these gentlemen has published a very valuable work illustrative of the subject. It may, however, be right to add, that the facts yet developed are too scanty to admit of any very accurate mode of theorizing in this branch of science. We may advert in the first instance to the effects which are found to arise from the action of coated surfaces on ferruginous bodies, as these were observed at a much earlier period.

Dr. Franklin appears to have been the first electrician who paid any serious attention to this subject. He sent the charge of some large jars through fine sewing-needles: the ends of the needles were rendered blue, and on being carefully laid on water they traversed, evincing evident proofs of polarity. The most remarkable circumstance attending these experiments was, that if the needle lay east and west when the charge was passed through it, the end which was entered by the fluid pointed to the north; but if it lay south and north, the end which lay pointing to the north would continue to do so, whether the charge entered by that end or the other; although the Doctor imagined that a still stronger charge would have reversed the poles, even in that situation, since this effect had been actually produced by lightning. The polarity he also found to be strongest when the needle received the charge while lying north and south, and weakest when it lay so as to point east and west.

But the experiments most to be relied on were made by Van Marum with the large machine and battery in the Tylerian Museum at Haarlem. He succeeded in giving polarity to needles made of watch-springs, of from three to six inches in length; and also to steel bars nine inches long, from a quarter of an inch to half an inch broad, and about a line in thickness. The result was, that when the bar was placed horizontally in the magnetic meridian, whichever way the shock entered, the end of it that stood towards the north acquired the north polarity, and the opposite end acquired the south. If the bar, before it received the shock, had polarity, and was placed with its poles contrary to the usual direction, its natural polarity was uniformly diminished, and often reversed; so that the extremity of it, which in receiving the shock pointed to the north, became the north pole.

When the bar was struck standing perpendicularly, its lowest end became the north pole in any case, even when the bar previously possessed magnetism, and was placed with the south pole downwards. Things remaining the same, the bars seemed to acquire an equal degree of magnetic power, whether they were struck whilst standing horizontally in the magnetic meridian, or perpendicular to the horizon. When the needle was placed in the magnetic equator, whichever way the charge entered, it never produced any magnetism; but if it was passed through its width, then the needle acquired a considerable degree of magnetism, and the end which lay towards the west became the north pole, and the other end the south pole. If a needle or bar, already magnetic, or a real magnet, was struck in any direction, its power was always diminished. For this experiment they used bars of considerable size and weight, one of which was 7·08 inches long, 0·26 broad, and 0·05 thick. When the shock was so strong in proportion to the size of the needle, as to render it hot, then the needle generally acquired no magnetism at all, or very little. These experiments were made with a battery composed of 135 jars, containing about 130 square feet of coated surface.

M. Von Buch, also, appears to have ascertained the action of common electricity in producing magnetism, without a previous knowledge of what had been done by others in that way, and he succeeded in producing the effect by a smaller power than had before been used for that purpose. He found that a strong discharge was not necessary, nor even a Leyden phial; but, fixing a helix between the prime conductor of a machine and another insulated conductor, placing a steel needle in it, and then drawing sparks from the latter conductor, the needle became magnetic. One single turn of a machine, with two discs, eighteen inches in diameter, was sufficient to make the needle evidently magnetic.

As the discharge of a considerable quantity of electricity through a wire seemed necessary to produce magnetism, it appeared probable that a wire electrified by the common machine would not occasion a sensible effect; and this was found to be the case, on placing very small needles across a fine wire connected with a prime conductor of a powerful machine, and the earth. But, as a momentary exposure in a powerful electrical circuit was sufficient to give permanent polarity to steel, it appeared equally obvious, that needles placed transversely to a wire at the time that the electricity of a common Leyden battery was discharged through it, ought to become magnetic, and this was actually the case, and according to precisely the same laws as in the voltaic circuit; the needle under the wire, the positive conductor being on the right hand, offering its north pole to the face of the operator, and the needle above exhibiting the opposite polarity.

So powerful was the magnetism produced by the discharge of an electrical battery of seventeen square feet, highly charged, through a silver wire of one-twentieth of an inch, that it rendered bars of steel two inches long, and from one-twentieth to one-tenth in thickness, so magnetic, as to enable them to attract small pieces of steel wire or needles; and the effect was communicated to a distance of five inches above or below or laterally from the wire, through water, or thick plates of glass, or metal electrically insulated.

The major part of the discoveries made in this science, have, however, been effected by galvanic electricity; and to this powerful agent, M. Oersted directed his attention about the commencement of 1807, when he proposed to try "whether electricity, the most latent, had any action on the magnet."

If a magnetic needle be left to take its natural direction, and then a straight portion of the connecting wire of a galvanic battery be brought above it, and parallel to it, that end of the needle next the negative pole of the battery moves towards the west; and that too whether the wire be on the one or the other side of the needle, so that it be above and parallel to it. If the connecting wire be sunk on either side the needle, so as to come into the horizontal plane in which the needle is allowed to move, there is no motion of the needle in that plane; but the needle, attempts to move in a vertical circle; and but for the imperfect suspension, and the influence of the earth's magnetism, would do so. When the wire is on the east of the needle, the pole of the needle next the negative end of the battery is elevated; and when on the west of the needle it is depressed. If the connecting wire be now sunk below the level of the needle, similar attractions and repulsions take place, but in opposite directions to those followed when it is above. The pole of the needle opposite the negative end of the battery then moves eastward, whatever the position of the wire, so that it be restricted as above.

That these positions of the magnetic needle may be retained with more facility in the memory, Professor Oersted proposed the following formula: "The pole above which the negative electricity enters is turned to the west; under which, to the east."

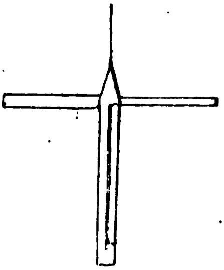
M. Oersted subsequently pointed out, what it is easy to see from the above experiments, that the movement of the needle took place in a circle round the connecting wire; and though, in the description of his first experiments, the quantity of declination given to the needle from the wire is expressed by an angle of so many degrees, yet it is afterwards stated to vary with the power of the battery. Whenever the needle is moved in a horizontal or any other circle from the position it naturally assumes, the power of the earth over it tends to restore that position, and is consequently an active force, in the present instance opposed to the power of the connecting wire; it therefore lessens the declination the needle would otherwise have. Also when the wire is brought into the same horizontal circle with the needle, its effect over it is shown by the elevation and depression of its opposite ends; and it is the mode of suspension combined with the earth's magnetic power that prevents it from traversing in a vertical circle. But if those interfering circumstances be removed, viz. if the suspension be such as to allow of free motion to the needle in every direction, and the earth's magnetism be rendered null, or counteracted either by the position of the needle, or by the vicinity of another magnet, then a much simpler idea of the relative movements of the wire and needle may be obtained.

It is not, perhaps, easy to obtain this perfect state of apparatus, but it is not difficult so to arrange it as to examine the movements first in one direction, and then in another. It will then be found, if the connecting wires of a sufficiently powerful apparatus be placed near a magnetic needle so as to pass near its centre, that the needle will arrange itself directly across the wire, whatever the previous position of the two; that if the wire be carried round the centre of the needle, or the centre of the needle round the wire, the same relative position of the two will continue; and that the direction of the needle across the wire is not indifferent, but has its poles always in a constant position to the poles of the battery. If the positive pole of a battery be on the right hand, and the negative pole on the left, and a wire be stretched between, connecting them, then a needle above the wire will point the north pole from, and the south towards us: or if below, the south pole from, and the north towards the experimenter.

If the connecting wire and the needle be represented by two small rods named accordingly, and fastened permanently together, then they will represent the wire and the needle in all positions; for, however one be placed, the other will correspond with it: or if, on the under side of a small square piece of glass, a line be drawn from top to bottom, the upper end being called negative and the lower positive; and on the upper surface a line be drawn from left to right, the left termination being named south, the right north; then the lower line will always represent the connecting wire, and the upper the needle.

The needle and wire being in this position, if the wire be moved along the needle towards either extremity, strong attractions will take place between it and the pole, notwithstanding the same part of the wire be employed; and the poles in the two positions are contrary to each other. In this case it appears that the same point in the wire has the power of attracting both the north and the south pole of the needle. If while the wire is thus situated near the end of the needle, the latter be turned round, so that the pole before there be replaced by the opposite pole, strong repulsions will take place; and that, to whichever pole the wire has in the first instance been carried, so that the same point which before attracted both poles will now repel them both. If, when the wire is near the extremity of the needle where the attraction is strongest, it be moved round the end so as to go from one side to the other, keeping the same point constantly towards the needle, its attractive power over the needle will be found to increase as it approaches the end, but remains on one side of it; will diminish as it turns the end; will become null when exactly opposed to the pole; and, as it passes on the other side, will resume repulsive powers, which will be strongest at the extremity of the pole on the opposite side to where the wire was situated at first.

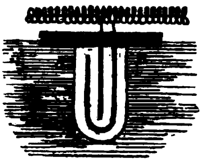
In one of the earliest experiments to show the motion impressed on a galvanic arrangement by the close proximity of a magnetized bar, Professor Oersted suspended a copper trough, furnished with a plate of zinc, exposing a surface of about two square feet. The apparatus was supported by a silk thread, and then charged with a strong acid solution. The wire which is seen to connect the two plates was then found to obey the magnet. It may be attracted or repelled, and is capable of producing similar effects on light steel needles, placed in the neighbourhood of the apparatus.



M. de la Rive's apparatus consists of a small galvanic combination attached to a cork; the plate of zinc is nearly half an inch wide, and extends about one and a half or two inches below its cork, its upper end passing through the same; the slip of copper is of equal width to the zinc, but passes round it, being thus opposed to both its surfaces, as in Dr. Wollaston's construction: its upper end also appears through the cork. A piece of copper wire, covered with silk thread, is coiled five or six times, and tied together so as to form a ring about an inch in diameter, and the ends of the wire are connected, by solder, one with the zinc, and the other with the copper slip above the cork.

When this small apparatus is placed in water slightly acidulated with sulphuric or nitric acid, the ring becomes highly magnetic, and will arrange itself in a plane perpendicular to the magnetic meridian, or it will at least indicate a tendency to take up that position; but the escape of the bubbles, arising from the decomposition of the water, prevents it from preserving a fixed direction.

Its magnetic qualities, however, are more obviously shown by bringing to it a strong magnet. When the result of the application is attraction, the cork will advance towards the extremity of the magnet; and if the latter be held horizontally, and in a line with the centre of the former, this will continue to advance till the pole of the magnet is within the ring, and then proceed with considerable velocity till it reaches the middle of the magnet, where it remains perfectly stationary. If now the magnet be withdrawn, and changed end for end, and re-introduced into the ring, the latter will go off from the magnet, turn itself round when quite free from it, again advance, and settle itself as before in the centre.

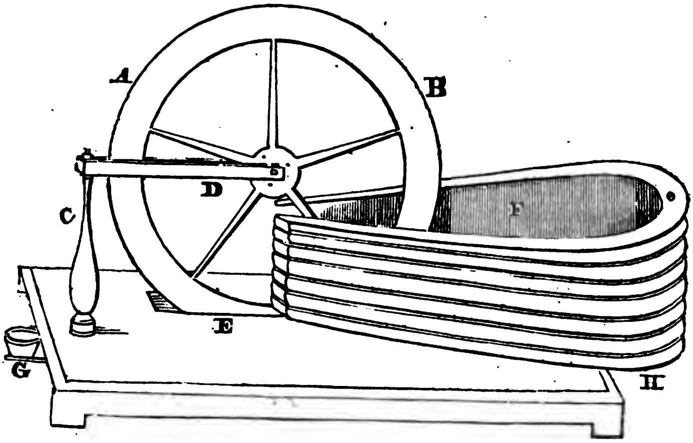


A perfect polar arrangement may be formed by the simple electro-magnetic apparatus, represented in the figure A B, which will be found to be attracted and repelled precisely in the same way as common magnets.

One of the most delicate pieces of apparatus for exhibiting electro-magnetic rotation, was suggested by Mr. Faraday. It is shown in the accompanying figure, and consists of a piece of glass tube, the bottom part of which is closed by a cork, and through it is passed a small piece of soft iron wire, so as to project above and below the cork. A little mercury is then poured in, to form a channel between the iron wire and the glass tube. The upper orifice is also closed by a cork, through which a piece of platinum wire passes, being terminated within by a loop; another piece of wire hangs from this by a loop, and its lower end, which

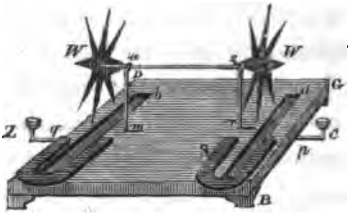
dips a very little way into the mercury, being amalgamated, it is preserved from adhering either to the iron or the glass. Things being thus arranged, a very minute galvanic power being applied by a contact with the lower and upper end of the apparatus, and the pole of a strong magnet being applied to the external end of the lower iron wire, the moveable wire within begins rapidly to rotate round the temporary magnet thus formed; and which rotation may be inverted either by changing the contact, or by inverting the magnet. Mr. Faraday states that this instrument is so sensible, that a rotation has been produced in it by two plates, each only one inch square.

Mr. Marsh has constructed an ingenious machine, in which he causes a wheel to revolve upon its axis, by the combined operation of electricity and magnetism. The

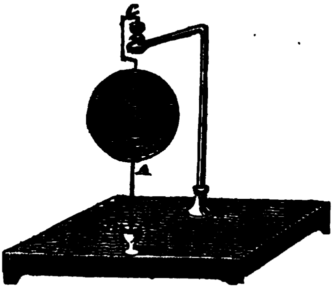


apparatus by which this motion is produced, is shown above. The rectangular base G H, is furnished with a brass pillar and arm C D, on which is allowed to rest the wheel A B. A cup, containing mercury, is placed at G, and by a metallic wire beneath, serves to connect the revolving wheel with one pole of the battery, while a similar cup, which is hid from view by the horse-shoe magnet, connects the opposite pole with the mercurial trough E. On placing the magnet in its proper situation, the wheel is found to revolve rapidly on its axis; and if the poles be changed, motion occurs in the opposite direction.

A very curious revolving apparatus may be constructed, by employing two horse-shoe magnets in connexion with the opposite poles of a powerful voltaic arrangement. It is represented in the annexed cut, and consists of a rectangular stand A B G D, having two grooves, about half an inch deep, cut in it parallel to its length. C *p*, Z *q*, are two wires having cups for connexion at Z and C, and each passing into its respective groove *a b*, *c d*, filled with mercury; into which are slightly immersed the points of the wheels W W′; these being fixed on an axle W W′, and resting upon the two supports *a s*, brought to a fine edge, in order to reduce the friction as much as possible, and to give the greater freedom of motion. N S are two horse-shoe magnets, posited as in the figure, with the like poles interior and exterior of the wheels. The apparatus being thus prepared, and the contact made at Z and C, the wheels will begin to rotate with great velocity.



A differently formed wire, and a more simple mode of



suspension, is shown in the accompanying diagram. Here a brass or copper wire C, rests at its bent end C, in a cup containing a little mercury, and is very moveable in azimuth round this point. The other end passes through the centre of a circular piece of pasteboard, and then forms a series of spiral turnings in the plane of this circular piece. The wire is attached by thread or silk to the pasteboard disc, and at the point A, it turns and descends till its extremity reaches the quicksilver in the cup B. The communication being now made at C and B, with the battery, the spiral will immediately arrange itself, in a plane perpendicular to the magnetic meridian.

M. Berzelius has described a curious experiment, which consists in placing a thin leaf of tin, eight inches long and two inches wide, parallel to, and in the plane of, the meridian, and in that position connecting it with the elements of a voltaic circle. A magnetic needle brought near the lower edge of this plate is thrown 20° from the magnetic meridian. On moving it slowly upwards, it takes its natural position, when level with the middle of the plate, except that it is raised at one end, and depressed at the other; and when near the upper edge, it moves from the magnetic meridian in the opposite direction to what it did below. When the needle is moved up and down on the opposite side of the plate, the same deviation and effects take place, but in opposite directions.

M. Ampere has proposed to construct a *telegraph*, by using as many conducting wires and magnetic needles as there are letters. By placing each letter on a different needle, he establishes, by means of the pile, placed far from the needles, an alternate communication betwixt its two extremities and those of each conductor, and thus forms a sort of telegraph, fitted for writing all the details which it may be wished to transmit through any obstacle, to a person who is charged with observing the letters placed on the needles. By placing on the pile a row of stops, which carry the same letters, and establish the communication by their descent, this method of correspondence, observes M. Ampere, might be made both easy and rapid.

Sir H. Davy found, that when two wires were placed in a basin of mercury, perpendicular to the surface, and in the voltaic circuit of a battery with large plates, and the pole of a powerful magnet held either above or below the wires, the mercury immediately began to revolve round the wire as an axis, and with a highly increased velocity when the opposite poles of two magnets were used, one being above and the other below. Masses of mercury, several inches in diameter, were thus put in motion, and made to revolve in this manner, whenever the pole of the magnet was held near the perpendicular of the wire; but when the pole was held above the mercury between the two wires, the circular motion ceased; and currents took place in the mercury in opposite directions, one to the right, and the other to the left of the magnet. Sir Humphrey next inverted the form of the experiment. He took two copper wires of about one-sixth of an inch in diameter, the ends of which were flat, and carefully polished, and passed them through two holes three inches apart, in the bottom of a glass basin, and perpendicular to it. They were cemented into the basin, and made non-conductors by sealing wax, except at the polished ends. The basin was then filled with mercury to the height of 1-11th of an inch above the wires. The moment the contacts were made, the mercury was seen in violent agitation; its surface became elevated to a small cone above each of the wires; waves flowed in all directions from these cones, and the only point of rest was apparently in the centre of the mercury between the two wires. On holding a powerful magnet some inches above one of the cones, its apex was diminished, and its base extended; by lowering the pole farther, these effects were increased, and the undulations became feebler; and at a smaller distance, the surface of the mercury became plain, and rotation slowly commenced round the wire. The elevations and depressions in some experiments were one-fifth or one-sixth of an inch.*

When a magnet is made to act on steel filings, these filings arrange themselves in curves round the poles, but diverge in right lines; and in their adherence to each other form right lines, appearing as spicula. In the attraction of the filings round the wire in the voltaic circuit, on the contrary, they form one coherent mass, which would probably be perfectly cylindrical, were it not for the influence of gravity. In first considering the subject, it appeared to Sir Humphry, that there must be as many double poles as there could be imagined points of contact round the wire; but when he found the north and south poles of a needle uniformly attracted by the same quarters of the wire, it appeared to him that there must be four principal poles corresponding to these four quarters. Dr. Wollaston has, however, pointed out that there is nothing definite in the poles: that the phenomena may be explained, by supposing a kind of revolution of magnetism round the wire, depending for its direction upon the position of the negative and positive sides of the electrical apparatus.

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* Vide Philosophical Transactions, 1823, p. 156.

To throw some light upon this matter, and to ascertain correctly the relations of the north and south poles of steel, magnetised by electricity to the positive and negative state, Sir Humphrey Davy placed short steel needles round a circle made on pasteboard, of about two inches and a half in diameter, bringing them near each other, though not in contact; and fastening them to the pasteboard by thread, so that they formed the sides of a hexagon inscribed within the circle. A wire was fixed in the centre of this circle, so that the circle was parallel to the horizon, and an electric shock was passed through the wire, its upper part being connected with the positive side of a battery, and its lower part with the negative. After the shock all the wires were found magnetic, and each had two poles; the south pole being opposite to the north pole of the wire next to it, and *vice versa*; and when the north pole of a needle was touched with a wire, and that wire moved round the circle to the south pole of the same needle, its motion was opposite to that of the apparent motion of the sun.

A similar experiment was tried with six needles arranged in the same manner, with only this difference, that the wire positively electrified was below. In this case the results were precisely the same, except that the poles were reversed: and any body, moved in the circle from the north to the south pole of the same needle, had its direction from east to west.

A number of needles were arranged as polygons in different circles round the same piece of pasteboard, and made magnetic by electricity; and it was found that in all of them, whatever was the direction of the pasteboard, whether horizontal or perpendicular, or inclined to the horizon, and whatever was the direction of the wire with respect to the magnetic meridian, the same law prevailed; for instance, when the positive wire was east, and a body was moved round the circle from the north to the south poles of the same wire, its motion (beginning with the lower part of the circle) was from north to south, or with the upper part from south to north; and when the needles were arranged round a cylinder of pasteboard so as to cross the wire, and a pencil-mark drawn in the direction of the poles, it formed a spiral.

It was perfectly evident from these experiments, that as many polar arrangements may be formed as chords can be drawn in circles surrounding the wire.

Supposing powerful electricity to be passed through two, three, four, or more wires, forming part of the same circuit parallel to each other in the same plane, or in different planes, it could hardly be doubted that each wire, and the space around it, would become magnetic in the same manner as a single wire, though in a less degree; and this was found to be actually the case. When four wires of fine platinum were made to complete a powerful voltaic circuit, each wire exhibited its magnetism in the same manner, and steel filings on the opposite sides of the wires attracted each other.

As the filings on the opposite sides of the wire attracted each other in consequence of their being in opposite magnetic states, it was evident, that if the similar sides could be brought in contact, steel filings upon them would repel each other. This was very easily tried with two voltaic batteries, arranged parallel to each other, so that the positive end of one was opposite to the positive end of the other: steel filings upon two wires of platinum joining the extremities strongly repelled each other. When the batteries were arranged in the opposite order, viz. positive opposite to negative, they attracted each other; and wires of platinum (without filings) and fine steel wire (still more strongly) exhibited similar phenomena of attraction and repulsion under the same circumstances.

As bodies magnetised by electricity put a needle in motion, it was natural to infer that a magnet would put bodies magnetised by electricity in motion; and this was found to be the case. Some pieces of wire formed of platinum, silver, and copper, were placed separately upon two knife edges of platinum, connected with the ends of a powerful voltaic battery, and a magnet presented to them; they were all made to roll along the knife edges, being attracted when the north pole of the magnet was presented, the positive side of the battery being on the right hand, and repelled when it was on the left hand, and *vice versa*, changing the pole of the magnet. Some folds of gold leaf were placed across the same apparatus, and the north pole of a powerful magnet held opposite to them; the folds approached the magnet, but did not adhere to it. On the south pole being presented, they receded from it.

Imperfect conducting fluids do not give polarity to steel when electricity is passed through them; but electricity passed through air produces this effect. Reasoning on this phenomenon, and on the extreme mobility of the particles of air, Sir Humphry Davy concluded that the voltaic current in air would be affected by the magnet.

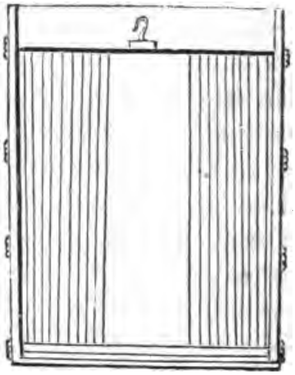
To put this important fact to the test of experiment, Mr. Pepys made arrangements for charging the great battery of the London Institution, consisting of 2000 double plates of zinc and copper, with a mixture of 1168 parts of water, 108 parts of nitrous acid, and twenty-five parts of sulphuric acid; the poles were connected by charcoal, so as to form an arc, or column of electrical light, varying in length from one to four inches, according to the state of rarefaction of the atmosphere in which it was produced; and a powerful magnet being presented to this arc, or column, having its pole at a very acute angle to it, the arc, or column was attracted or repelled with a rotatory motion, or made to revolve by placing the poles in different positions, being repelled, when the negative pole was on the right hand, by the north pole of the magnet, and attracted by the south pole, and *vice versa*.

The same ingenious philosopher placed some silver wire of one-twentieth of an inch, and some of one-fiftieth, in different parts of the voltaic circuit when it was completed, and shook some steel filings on a glass plate above them: the steel filings arranged themselves in right lines, always at right angles to the axis of the wire. The effect was observed, though feebly, at the distance of a quarter of an inch above the thin wire, and the arrangement in lines was nearly to the same length on each side of the wire.

He ascertained, by several experiments, that the effect was proportional to the quantity of electricity passing through a given space, without any relation to the metal transmitting it; indeed, it may be added, that the finer the wires, the stronger their magnetism.

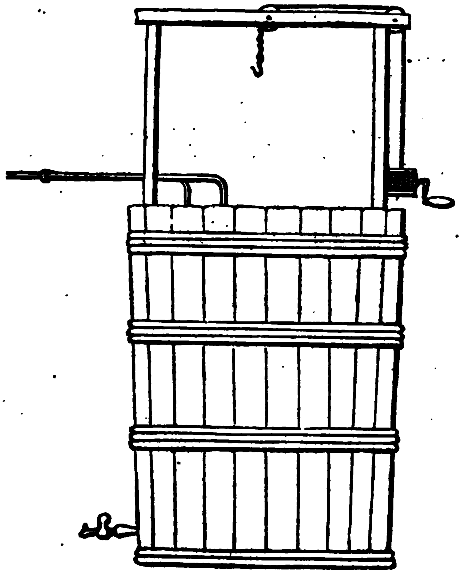
A zinc plate of a foot long, and six inches wide, arranged with a copper plate on each side, was connected by a very fine wire of platinum; and the plates were plunged an inch deep in diluted nitric acid. The wire did not sensibly attract fine steel filings. When they were plunged two inches, the effect was sensible; and it increased with the quantity of immersion. Two arrangements of this kind acted more powerfully than one; but when the two were combined, so as to make the zinc and copper plates but parts of one combination, the effect was very much greater. This was shown still more distinctly in the following experiment:—Sixty zinc plates with double copper plates were arranged in alternate order, and the quantity of iron filings which a wire of a determined thickness took up, observed: the wire remaining the same, they were arranged so as to make a series of thirty. The magnetic effect appeared more than twice as great; that is, the wire raised more than double the quantity of iron filings.

The most powerful galvanic arrangement for electromagnetic purposes generally, that has yet been described, was constructed under the direction of Mr. Pepys. A section of the apparatus is shown in the accompanying engraving.



It forms a coil, and consists of two plates, each fifty feet in length, and two feet in width; the one copper, and the other zinc, making a superficial surface of 4000 feet. They are rolled round a cylinder of wood, with three strands or ropes of horse-hair between each plate, to prevent contact of the metals; and, to maintain these in their situation, notched sticks are occasionally introduced in the rolling. Two conductors of copper, near three-fourths of an inch in thickness, are firmly attached to the end of each plate, from which the power is dispensed upon immersion in the acid.

The entire apparatus may be best illustrated by another figure.



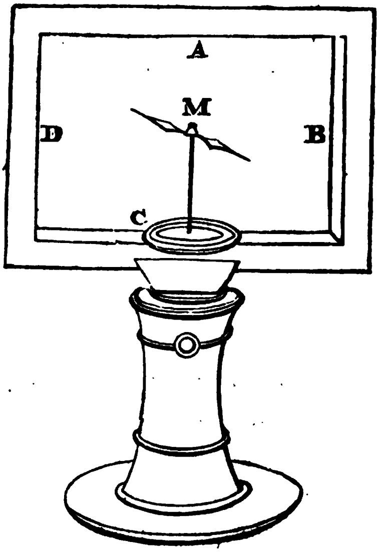
Rather more than fifty gallons of dilute acid are requisite to charge the receptacle intended for the metallic spiral; and to put the apparatus in operation, the coil is gradually lowered into the tub beneath. The immersion of the spiral, however, displaces a certain portion of water; so that, when a balance is resorted to, it is necessary to restore the equilibrium by withdrawing one of the counter-weights.

As a mere electrical battery, the effect to be derived from this pair of plates is comparatively small; but its powers as an agent for illustrating the connexion between magnetism and electricity are truly astonishing.

Magnetic needles, placed at a distance of several feet from the apparatus, were readily put into motion, and deflected from their previous position. The most singular phenomenon, however, which resulted from the series of experiments with this extraordinary instrument, remains to be noticed:—A spiral of wire was connected with the two poles of the battery, and being placed in a perpendicular direction, a steel cylinder was dropped from the upper end, and this, instead of obeying the ordinary laws of gravitation, was found, after a few oscillations, to take a position somewhere midway between the two extremities of the tube.

A slight view of the apparatus employed in *thermo-electricity*, must complete the present sketch.

In 1823, Dr. Seebeck, of Vienna, by combining metals of different kinds, succeeded in producing deflections of the magnetic needle by an increase of temperature alone, without any assistance from the voltaic arrangement before used. Dr. Seebeck's apparatus consisted of a parallelogram, A B D, composed of two metals, bismuth and antimony; one long and one short side being formed of each metal. On placing the needle, M, on a stand and centre



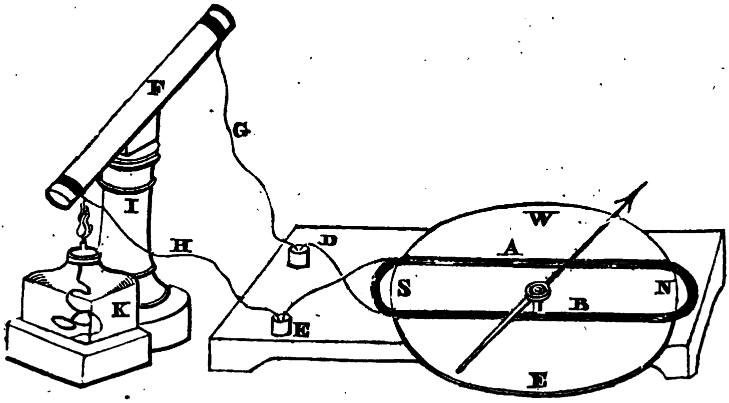
C, and allowing it to arrange itself in the magnetic meridian, it was found that the application of a spirit-lamp to either extremity, produced a change in its situation.

The following table of thermo-electrics is furnished by Professor Cumming: and when brought in contact, each substance is positive to all below, and negative to all above. The voltaic series, and the order of conductors of electricity and heat, are added merely to show that the thermo-electric series has but little accordance with either of them.

Thermo-electrics.	Voltaic Series.	Electricity.	Heat.
Bismuth.	Charcoal.	Silver.	Silver.
Mercury.	Platina.	Copper.	Gold.
Nickel.	Gold.	Lead.	Tin.
Platina.	Silver.	Gold.	Copper.
Palladium.	Copper.	Zinc.	Platina.
Cobalt.	Lead.	Tin.	Iron.

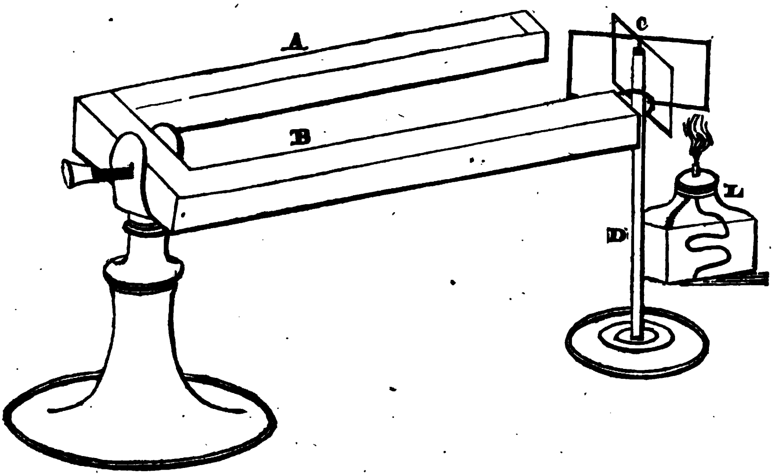
Thermo-electrics.	Voltaic Series.	Electricity.	Heat.
Silver.	Tin.	Platina.	Lead.
Tin.	Iron.	Palladium.	
Lead.	Zinc.	Iron.	
Rodium.			
Brass.			
Copper.			
Gold.			
Zinc.			
Charcoal.			
Plumbago.			
Iron.			
Arsenic.			
Antimony.			

The next apparatus to be described, was contrived by Professor Cumming, and exhibits the combined effects of heat, electricity, and magnetism. It consists of a small convoluted wire, covered with black silk, and its ends terminate in two small cups, containing mercury. When required to act, two pieces of wire, one silver and the other platina, twisted together at one end, and the others introduced into the cups, are heated by a spirit-lamp, and a needle placed in the coil may readily be deflected. A better arrangement may be illustrated by the accompanying wood-cut.



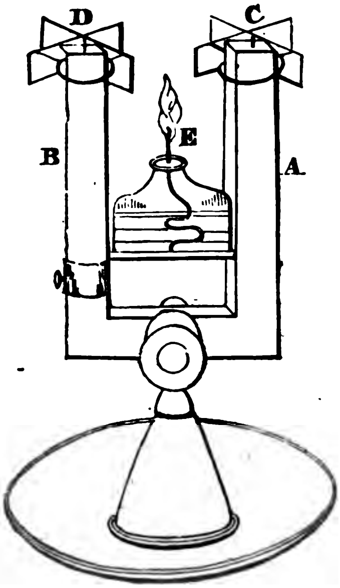
It consists of a cylinder of bismuth or zinc, F, with copper wires twisted round each end, as at G, H. The instant the flame of the spirit-lamp K, is applied to one end of the bar, the magnet is deflected in one direction, but upon heating the other end by changing the position of the lamp, the needle returns towards the convoluted wire, and passing it, exhibits the same degree of deflection on the opposite side.

But a rotatory motion may be produced in the thermo-electric apparatus, as well as in that which owes its power to the voltaic battery.



The parallelograms which cross each other in this apparatus, are each composed of two pieces of metal, the lower side being platinum, and the other three sides silver. A horse-shoe magnet A B, being placed near the apparatus as represented in the figure, and the flame of a spirit-lamp L, applied to one of the angles of the transverse parallelogram C, it instantly begins to revolve with considerable rapidity.

A double motion may be produced by a modification of the preceding apparatus.



When the heat of the flame E, acts upon D and C, in this ingenious arrangement, the double parallelograms will revolve with great rapidity, but they turn in opposite directions, in consequence of the opposite polarity of the horse-shoe support.

M. Ampere ascribes the diurnal variation of the needle to the corresponding motion of the globe, which produces a continued variation in its temperature. And to this he says, " We must also add, among the electro-motive actions of the different parts of the earth, that of the magnetic minerals which it contains, and which should be considered as so many voltaic piles. The elevation of temperature which takes place in the conductors of electric currents, ought also to take place in those of the terrestrial globe.

METEOROLOGY.

Construction of Meteorological Instruments.—Pressure of the Air as indicated by the Mercurial Column.—Barometer.—Thermometric Instruments.—Pyrometer.—Hygrometer.—Apparatus by Daniell and Leslie.—Rain-gauge.—Anemometer.

THE materiality of the gaseous elements which constitute the atmosphere, has already been proved by a reference to their weight, and consequent pressure on the earth's surface. The pneumatic equilibrium is, however, continually destroyed, and we seldom find the mercurial column at the same altitude for any considerable length of time. But the variable character of the atmosphere is not confined to a change in its density: it is surcharged with moisture at one period, while at another it is found in an arid and burning state. To acquire a practical knowledge of the science, therefore, it will be necessary to notice the apparatus by which the meteorologist is enabled to furnish the data on which it is founded. The principal instruments in use in meteorology, are the barometer, by which the atmospheric pressure over any place is known; the thermometer, which ascertains the temperature of the air; the hygrometer, to indicate the moisture or dryness of the air; the pluviameter, or rain-gauge, to measure the depth of rain that falls; the wind-dial, to point out the direction of the wind; and the anemometer, to measure its force.

We may commence with the barometer, which owes its power of foretelling changes in the weather to the mechanical operation of the air.

The great value of this instrument in meteorology will be a sufficient apology for describing its construction, especially as its principle will then be fully understood.

The tubes of which barometers are made, ought to be about one-third of an inch in diameter, and the one end hermetically sealed or closed, prior to its being removed from the glass-house. The mercury also must be perfectly pure, and should be freed from air by boiling in a glass vessel. To fill the tube with mercury, it should be first warmed, and the fluid metal may then be introduced by means of a small paper funnel. When the tube is nearly filled, small bubbles of air will be observed adhering to the glass; and to dissipate these, it will be necessary to close the open end of the tube with the finger, and then invert it. On again bringing the tube to its original situation, the air-bubbles will unite, and by their buoyancy ascend through the quicksilver, taking with them the smaller bubbles in their passage; should any air remain, this operation may be repeated, and the tube then filled to the top. The open end of the tube must now be immersed in a basin of mercury, and on withdrawing the finger, the fluid metal will subside in the tube, remaining suspended at the height of about twenty-nine or thirty inches.* To complete the barometer, it will only be necessary to attach the basin and tube to a board placed in a perpendicular direction, having a scale of inches at the upper end, accurately measured from the surface of the mercury in the cistern; and by the oscillations in the mercurial column, we ascertain the amount of pressure on the vessel beneath.

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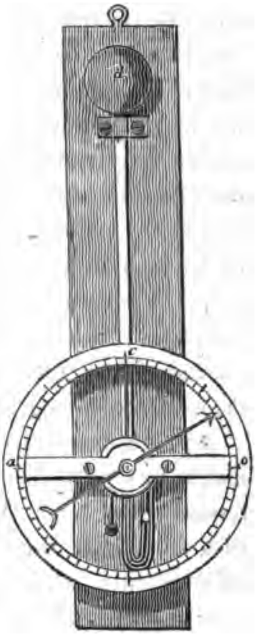
* It has long been known that an atmosphere of mercury exists in the upper part of the barometer, having a very small degree of tension; and Mr. Faraday has shown, by the following simple experiment, that a mercurial atmosphere may exist without removing the air. A small portion of mercury was put through a funnel into a clean dry bottle, capable of holding about six ounces, and formed a stratum at the bottom, not one-eighth of an inch in thickness: particular care was taken that none of the mercury should adhere to the upper part of the inside of the bottle. A small piece of leaf-gold was

M. Pugh, in his Observations sur la Pesanteur de l'Atmosphere, directs, that to remedy the inconveniencies attendant upon the upright barometers, a graduated ruler should be applied parallel to the tube, having its lower end floating on the surface of the mercury in the cistern, according to the motion of which the scale will ascend or descend. Two or three supports, through which the ruler may pass so as to move freely, will be sufficient to keep it parallel to the column of mercury, whose length will be always visible; but for greater exactness, a moveable index, with a vernier, may be adapted to the scale, in such a manner that one end shall be on a level with the surface of the mercury in the tube, while the vernier indicates the exact measure of the column.

A very simple mode of enlarging the divisions of the barometer, is commonly ascribed to Sir Samuel Moreland. It consisted in bending the upper part of the tube into a very oblique position. By this plan, however, the scale, which depends on the perpendicular altitude, cannot be augmented beyond three or four times, without incurring evident risk of inaccuracy. This instrument is called the inclined, or diagonal barometer.

then attached to the under part of the stopper of the bottle, so that when the stopper was put into its place, the leaf-gold was inclosed in the bottle. After the lapse of six or eight weeks, it was examined, and the leaf-gold was found whitened by a quantity of mercury, which had evidently ascended from beneath.

The wheel-barometer is very generally employed, though its indications are not so accurate as the simple tube already described. It is represented in the accompanying diagram. The tube is furnished with a large round head or ball, turned up at bottom; and upon the surface of the mercury in the recurved leg, there is placed a short glass tube loaded with mercury, with a string going over a pulley, and this is balanced by another weight, hanging freely in the air. As the surface at *d*, is large, and that at the lower extremity very small, the motion of the quicksilver, and, consequently, of the ball at bottom, will be very considerable; but as the weight moves up and down, it turns the pulley, and that gives motion to a hand or index; thus, by the divisions of a large graduated circle, the minutest variations of the air are shown, at least, if the instrument be accurately made, and the friction of the various parts inconsiderable.



But wheel-barometers may be constructed so as to avoid most of the defects hitherto thought unavoidable in such instruments. Let a solid piece of glass, in the form of a pear, float upon the surface of the mercury in the tube: to the bottom of this ball let a piece of thread be attached, which may descend quite through the column of mercury, and pass round a pulley placed under the orifice of the tube, from thence, it must proceed to a second pulley, placed parallel to the former in the cistern, and afterwards over the pulley in the centre, which gives motion to the index: at the extremity of this thread must be fixed another small solid ball of glass, to give motion to the index when the mercury descends. On account of the two pullies, it will be necessary to make the cistern of such a size, that if the column of mercury should experience the whole extent of the variation, the height of the mercury in the cistern may suffer no visible change: thus, suppose that the diameter of the cistern is four inches, the total variation of the column will occasion a difference of 1-24th part of an inch in the height of the mercury in the cistern, which is equivalent to an angle of five degrees formed by the index; but if the diameter of the cistern be six inches instead of four, the difference will not exceed 1-48th of an inch, corresponding to an angle of two degrees and a half.

An ingenious and very substantial kind of marine-barometer, was recommended by Blondeau, one of the Professors of the Naval Academy at Brest. It consisted of an iron tube, bent below into a syphon, and filled carefully with mercury, which carried a float. For this purpose, a musket-barrel, about three feet long, was chosen, having a very smooth and even bore, and an iron breech closely welded to it, instead of being soldered with brass, which might become corroded by the action of the mercury. The lower end of the tube had a collar of leather, to which was screwed a piece of iron, perforated through its whole length, and bent into an arch, having a vertical cylinder of iron, four inches high, and of the same bore exactly as the tube, screwed at the other extremity. The contracted aperture at the end of the tube, not being exactly in the middle, was not always opposite that of the arch; and, therefore, by turning it occasionally aside, the communication could be contracted at pleasure, or even cut off entirely. The cylindrical piece was tapered at the top to a narrow orifice, through which an iron wire, attached to a small ivory float, had been introduced. To prepare this instrument for action, the mercury was first boiled in the tube; then the arch, filled with hot mercury, was screwed to the end, the cock opened, and the surplus mercury allowed to flow over; next, the vertical piece, with its float, was screwed on, and a little mercury added. The origin of the scale was to be determined from the comparison with another good barometer of the ordinary construction; but, owing to the equality of the bores of the opposite tubes, the divisions were only half the usual size, or the inches were exhibited by half inches.

This species of barometer is certainly free from all sort of risk, while the facility which, by means of turning the arch, it affords in checking the ascent and descent of the mercury, prevents, in a great measure, the oscillations of that fluid. If the instrument were properly suspended, therefore, its indications would be tolerably steady and regular. The chief objection to it, however, consists in the diminutive range of its scale.

The following rules are the result of a series of comparative observations made with the barometer.

The barometer rising, may be considered as a general indication that the weather is becoming finer.

The atmosphere apparently becoming clearer, and the barometer above rain, and rising, show a disposition in the air for settled fair weather.

If, during a continued series of cloudy and rainy weather, the barometer rise gradually, though it remain below rain, especially if the wind changes from the south or west towards the north or east points, clear and dry weather may be expected.

The weather for a short period, viz. from morning until evening, may commonly be foretold with a considerable degree of certainty. If the barometer has risen during the night, and is still rising, the clouds are high, and apparently dispersing, and the wind calm, especially if it be in or about the north or east points, a dry day may be confidently expected. The same rule applies for predicting the weather from evening till morning.

During the increase of the moon there seems to be a greater disposition in the air for clear dry weather than in the wane; but this disposition does not usually commence till about three or four days after the new moon, and ceases about three or four days after the full moon.

The barometer should be observed at least three times in the day, or oftener, when the weather is changeable, in order to ascertain whether the mercury be stationary, rising, or sinking; for, from this circumstance, together with the direction of the wind, and the apparent state of the air at the time, is information to be collected; and a continuance of the same, or a sudden change of the weather to be foreseen.

Lastly. The higher the mercury stands in the scale in each instance, and the more regularly progressive its motion, the more conclusive will be the indication; and the more the wind inclines towards the north or east points, the greater will be the disposition in the air for fair weather. The indications of rainy weather will obviously be the direct reverse of those rules which predict fair weather. Frost is indicated in winter by the same rules that indicate fair weather; the wind being in or about the north or east points, and the thermometer sinking towards 32. A fall of snow seldom comes without a previous frost of some duration, and is indicated by the sinking of the barometer, especially if the mercury be below changeable, and the thermometer at or near the freezing point. When the temperature of the air is about 35, snow and rain sometimes fall together; at a warmer temperature than 35, it seldom snows, or rains at a colder temperature. Thunder is presaged by the same rules which indicate rain, accompanied by sultry heat; the thermometer being up to 75. Storms, hurricanes, and high winds, are indicated by the barometer falling suddenly, or sinking considerably below much rain. The barometer is known to be rising or sinking, by the mercury having either a convex or concave surface: at any time, however, the weather may differ widely from the indications of the barometer, as it is sometimes known to happen, that a particular spot is affected by local circumstances. After a long-continued series of wet weather, we may, when the weather becomes fine, expect an uninterrupted continuance of dry weather. If, after a long series of wet weather, the barometer rise above changeable, and the wind veer steadily towards the north or east points, a continued duration of fair weather may be expected. Slow and progressive variations in the barometer, with a fixed and steady state of the wind, indicate permanency with the change.

The influence of heat will account for the semi-diurnal variations of the barometer, which are observed especially within the torrid regions. From ten o'clock in the morning till four in the afternoon, the mercury generally falls; but, after that hour, it rises again, till ten o'clock at night, when it sinks till four in the morning, and then ascends till ten in the morning. These regular changes, which amount to about the five-hundredth part of the whole atmospheric pressure, depend on the prevalence of the alternating land and sea-breezes, occasioned by the diversified action of the sun's rays upon the earth and water. The accumulation of air is greatest at four o'clock in the morning and evening, and the mercury then attains its highest point; but it sinks lowest at ten o'clock in the morning and evening, when the incumbent mass has been the most reduced.

The regular decrease in the pressure of the atmosphere, which invariably arises from an increase of altitude, has suggested the employment of the barometer as a test for ascertaining the heights of mountains. Its fitness for this purpose may readily be explained by reference to the mechanical arrangement of the atmosphere, for we have seen that air possesses a gravitating force similar to that of all other fluids; the lowermost layer, or that which is nearest to the surface of the earth, being pressed with the whole weight of that which is piled above. Now it will be evident, that as we ascend a mountain, and as such, arrive at a higher stratum in the atmosphere, the column of air will decrease in altitude, and, consequently, its pressure will be diminished in a proportionate degree. So that, if we observe the amount of fall which takes place in the barometer at a given height, a similar fall will indicate a similar altitude at any other period.

We are indebted to Pascal for this application of Torricelli's tube. He made his first experiment in 1648, upon the Puy de Dome, a mountain 3565 feet in height, near Clermont, in France; and in the course of his ascent, he found the column continue to descend, till, on attaining the summit, it had sunk three inches and a half, which may be considered as the difference of atmospheric pressure between the summit and base.

At the surface of the earth, the mean density, or pressure, is considered equal to the support of a column of mercury thirty inches high.

At 1000	feet above the surface, the column falls to	28.91
2000	ditto	27.86
3000	ditto	26.85
4000	ditto	25.87
5000	ditto	24.93
1 mile	ditto	24.67
2	ditto	20.29
3	ditto	16.68
4	ditto	13.72
5	ditto	11.28
10	ditto	4.24
15	ditto	1.60
20	ditto	0.95

It may be proper to add, that the barometer descends in a geometrical ratio for equal ascents in the atmosphere, subject to a correction for the decreasing temperature of the elevation.

It has been argued by some philosophers, that, however excellent this instrument is as an indicator of the weather, much surer indications may be drawn from the animal world. Their various motions, the uneasiness under which they labour, and the precautions they take previously to any atmospheric variation, not only strikingly discover the acuteness of their feelings, and their extreme susceptibility of the impressions of natural causes, but also convey accurate prognostications of a change in the weather. That this was a circumstance not unknown to the ancients, is evident from several of their writings, and particularly from the Georgics of Virgil, in which it is observed that cows and various other animals are uncommonly affected before rain. Several others have also been remarked for this discriminating faculty; but the animal which appears, from a long series of regular and diligent observations, best entitled to notice, is the horse-leech; and it may be right to record a few remarks on its peculiarities. In fair and frosty weather it lies motionless, and rolled up in a spiral form at the bottom of the glass; but prior to rain or snow, it creeps up to the top, where, if the rain is likely to be heavy, or of some continuance, it remains a considerable time; if trifling, it quickly descends. Should the rain or snow be likely to be accompanied with wind, it darts about with amazing celerity, and seldom ceases until it begins to blow hard. If a storm of thunder and lightning be approaching, it is exceedingly agitated, and expresses its feelings in violent convulsive starts, at the top or bottom of the glass or vessel in which it is placed.

No person who has paid any attention to meteorology, can be ignorant of the great importance of ascertaining the precise quantity of moisture that exists in the atmosphere. There are a variety of instruments employed for this purpose, under the names of *hygrometers* or *hygroscopes.*

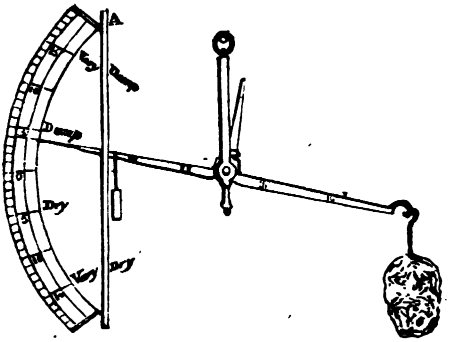
The most simple hygrometer is formed of the beard of the wild oat. If this be attached to a graduated dial, and a piece of straw connected with the opposite end to serve as an index, the straw will be found to pass over the dial, and by its change of situation, mark the hygrometric character of the atmosphere.

The substance which is found to possess by far the most delicate sensibility, and extensive range as an hygrometer, is the internal membrane of the Arundo Phragmites. A small bag, made of this membrane, is attached to the lower end of a thermometer tube, so as to form, as it were, its bulb. It is then filled with quicksilver, which rises, or falls, in consequence of the contraction or dilation of the membrane, by any change of moisture; and these changes are indicated upon a scale attached to the tube, the zero of this scale marking absolute humidity, and the other extremity of the scale absolute dryness. The lower end of the glass tube, instead of being merely inserted in the top of the bag, may pass through it, the quicksilver in the bag communicating with that in the tube by one or more openings made through the sides of the tube. By this means, the bag is supported by this glass, and prevented from being injured by any slight accident; and the instrument is also less affected by any change of temperature.

A convenient portable hygrometer may be made, by employing a slip of this membrane, and attaching its extremities to the end of a lever, somewhat like the small pocket metallic thermometers. Although this membrane is not entirely free from the change to which all animal and vegetable substances are liable, yet hygrometers made of it possess a considerable degree of uniformity.

Saussure contends for the superiority of human hair, for the purposes of hygrometers. Hair, he states, after it has been boiled in a weak alkaline lixivium, will expand by moisture nearly 1-40th of its length, and contract again by dryness; and that it is less liable to lose this effect by time than most other substances, and is moreover, from its tenuity, very quickly brought to the same state as the atmosphere. On these accounts, he gave it the preference to other substances, and constructed his hygrometers with it accordingly. The principle of the construction is to fasten one end of the hair to a fixed point, and the other to the arbour of a small wheel, which carries a fine needle at one extremity; this needle points out, upon a graduated circular arch, the hygrometric degrees. The hair is stretched by a counterpoise of three or four grains, suspended from the same arbour by a silk thread.

The *sponge-hygrometer* is represented in the accompanying diagram. It consists of a sponge, suspended by a fine thread of silk upon the beam of a balance, and exactly counterpoised on the other side, by a weight, so adjusted, as to cause an index or hand to point to the middle of a graduated arch, when the air is in a middle state, or rather, between the greatest moisture, and extreme dryness. Now, if the air become moist, the sponge growing heavier, will preponderate: if dry, it will, on the contrary, be raised, and show the increase or decrease of humidity in the air.



To prepare the sponge, it may be advisable to wash it first in water, and afterwards in a saline solution, as the deliquescent salts will take moisture from the atmosphere more readily than the sponge without such a provision.

Professor Leslie's apparatus may be thus described.

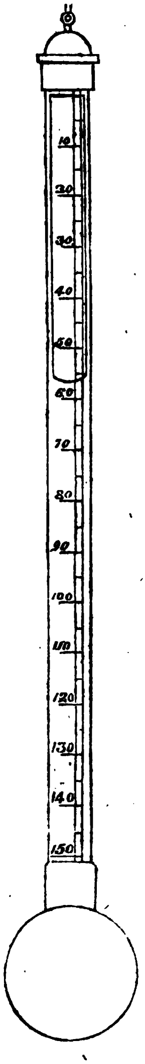
A piece of fine-grained ivory, about an inch and a quarter in length, was turned into an elongated spheroid, as thin as possible, weighing eight or ten grains, but capable of containing, at its greatest expansion, about three hundred grains of mercury; and the upper end, which was adapted to the body by means of a delicate screw, had a slender tube inserted, six or eight inches long, and with a bore of nearly the fifteenth part of an inch in diameter. The instrument being now fitted together, its elliptical shell was dipped into distilled water, or wrapped round with a wet bit of linen, and after a considerable interval of time, filled with mercury to some convenient point near the bottom of the tube, which forms the beginning of the scale. The divisions themselves were ascertained by dividing the tube into spaces, which correspond, each of them, to the thousandth part of the entire cavity, and equal to the measure of about three-tenths of a grain of mercury. The ordinary range of the scale included about seventy of those divisions. To the upper end of the tube was adapted a small ivory cap, which allowed the penetration of air, but prevented the escape of mercury, and thereby rendered the instrument tolerably portable.

This hygroscope was readily, though rather slowly, affected by any change in the humidity of the atmosphere. As the air became drier, it attracted a portion of moisture from the shell or bulb of ivory, which suffering, in consequence, a contraction, squeezed its contained mercury so much higher in the tube. But if, on the contrary, the air inclined more to dampness, the thin bulb imbibed moisture, and swelled proportionably, allowing the quicksilver to subside towards its enlarged cavity. These variations, however, were very far from corresponding with the real measures of atmospheric dryness or humidity. Near the point of extreme dampness, the alterations of the hygroscope were much augmented; but they diminished rapidly, as the mercury approached the upper part of the scale. The contraction of the ivory answering to an equal rise in the dryness of the air, was found to be six times greater at the beginning of the scale than at the seventieth hygroscopic division; and seemed, in general, to be inversely as the number of hygrometric degrees, reckoning from 20, below. Mr. Leslie placed, therefore, another scale along the opposite side of the tube, the space between the zero and the seventieth division of the hygroscope being distinguished into 100 degrees, and corresponding to the unequal portions from the number 20 to 120 on a logarithmic line. The scale might probably be extended farther by continuing the logarithmic divisions. Thus, 320 degrees by the hygrometer, would answer to 108 of the hygroscope, or to a contraction of 108 parts in a thousand in the capacity of the bulk.

We are also indebted to Professor Leslie for a very ingenious, but fragile instrument, called an *atmometer*.

It is intended to measure the quantity of moisture exhaled from any humid surface in a given time; and consists of a thin ball of porous earthenware, represented in the accompanying figure. It is usually from one to three inches in diameter, having a small neck firmly cemented to a long tube of glass, to which is adapted a brass cap, with a narrow collar of leather to fit close. Being filled with pure or distilled water, the descent of this column serves to indicate the quantity of evaporation from the external surface of the ball. The tube is marked downwards, through its whole length, by the point of a diamond, with divisions across it, each of which corresponds to a ring of fluid that, spread over the whole exhaling surface, would form a film only one-thousandth part of an inch in thickness. This graduation is performed by previously sealing one of the ends of the tube with wax, and introducing successive portions of quicksilver, to mark every twenty, fifty, or one hundred of those divisions; being calculated of equal bulk to discs of water, that have the surface of the ball (exclusive of the neck) for their base, and so many thousand parts of an inch for their altitude.

The instrument being thus constructed, has its cavity filled with pure water, and its cap screwed tight, and is then suspended freely, out of doors, sheltered indeed from rain, but exposed to the action of the wind. The water transudes through the porous substance of the ball, just as fast as it evaporates from the external surface; and this waste is measured by the corresponding descent of the liquid in the stem. At the same time, the column is suspended in consequence of the tightness of the cap, and prevented from oozing so freely as to drop from the ball. As the process of evaporation goes on, minute globules of air, separated by the removal of atmospheric pressure from the body of the water, or partly introduced by external absorption, continue to rise in fine streamlets to the top, where they partially occupy the space left by the subsidence of the fluid column. We need scarcely observe, that, after

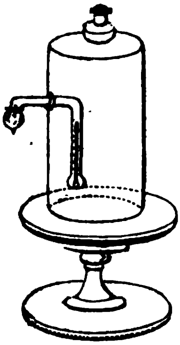


the water has sunk to the bottom of the stem, it will be requisite again to fill the cavity.

Mr. Daniell's hygrometer consists of two thin glass balls of 1¼ inch diameter, connected together by a tube, having a bore of about 1-8th of an inch. The tube is bent at right angles over the two balls, and the arm contains a small thermometer, whose bulb, which should be of a lengthened form, descends into the ball. This ball, having been about two-thirds filled with ether, is heated over a lamp till the fluid boils, and the vapour issues at the capillary tube which terminates the ball. The vapour having expelled the air from both balls, the capillary tube is closed hermetically by the flame of a lamp. The other ball is now to be covered with a piece of muslin. The stand should be of brass, and the transverse socket elastic, so as to hold the glass tube. A small thermometer is inserted into the pillar of the stand.

The manner of using the instrument may be thus described. After having driven all the ether into the ball by the heat of the hand, it is to be placed in an open window, or out of doors, with the balls so situated, as that the surface of the liquid may be upon a level with the eye. A few drops of ether are then to be poured upon the covered ball. Evaporation immediately takes place, which producing cold upon the ball, causes a rapid and continuous condensation of the ethereal vapour in the interior of the instrument. The consequent evaporation from the included ether, produces cold in the ball, the degree of which is measured by the thermometer. This action is almost instantaneous, and the thermometer begins to fall in two seconds after the ether has dropped. The artificial cold thus produced, causes a condensation of the atmospheric vapour upon the ball, which first makes its appearance in a thin ring of dew coincident with the surface of the ether. The degree at which this takes place is to be carefully noted. A little practice may be necessary to seize the exact moment of the first deposition, but certainty is very soon acquired. It is advisable to have some dark object behind the instrument, such as a house or a tree, as the cloud is not so soon perceived against an open horizon. The depression of the temperature is first produced at the surface of the liquid where evaporation takes place, and the currents which immediately ensue to restore the equilibrium, are very perceptible. The bulb of the thermometer is not quite immersed in the ether, that the line of greatest cold may pass through it. The greatest difference that Mr. Daniell observed in the course of four months' daily experiments, between the external thermometer and the internal one at the moment of precipitation in the natural state of the atmosphere, was 20 degrees. In very damp weather, the ether should be slowly dropped upon the ball; otherwise the descent of the thermometer is so rapid as to render it impossible to be certain of the degree. In dry weather, on the contrary, the ball requires to be well wetted more than once to produce the requisite degree of cold.

Mr. Daniell proposes to employ the same apparatus for artificial atmospheres. The arrangement of his instrument for this purpose may be adverted to. It will be seen that the bell-glass is perforated at the side, through which the tube, proceeding from the ball placed under it, containing the thermometer, is passed, and welded with the tube proceeding from the other ball on its exterior side, by means of a lamp: the stem is then secured in the side of the glass by means of cement, and the ether boiled, and the capillary opening secured as before directed. The exterior ball



is then to be covered with muslin. In this way, the evaporation from the latter produces a corresponding degree of cold upon the ball under the bell-glass, and will measure the quantity of vapour included, by the precipitation, which may readily be marked. The hygrometric properties of any substance may thus be easily measured, by placing it under the receiver, and marking the absorption of the vapour.

The following table may be considered as forming a fair average estimate of the hygrometric state of the atmosphere:

January	7.93
February	8.52
March	10.27
April	11.39
May	12.38
June	13.10
July	12.42
August	12.68
September	11.72
October	11.15
November	10.02
December	9.75

In connexion with the subject now under consideration, we may place Mr. Howard's classified view of the clouds. These vaporous exhalations appear to be generally sustained in the atmosphere by the united agencies of heat and electricity.

Gay Lussac ascribes the suspension of clouds to ascending currents, which push them upwards, until this force is balanced by the weight of the cloud. A soap-bubble, he remarks, will not rise in a room, but will descend directly when left to its own weight: but if the bubble is blown in the open air above a heated soil, it will rise to a considerable height.

The different forms of the clouds are thus described:—

1. *Cirrus.*—A cloud resembling a lock of hair, or a feather, with diverging fibres.

2. *Cumulus.*—A cloud which increases from above, in dense, convex, or conical heaps.

3. *Stratus.*—An extended, continuous, level, sheet of cloud, increasing from beneath.

These three, Mr. Howard denominates simple and distinct modifications, constituting the elements of every other variety; the two next are of what he calls an intermediate nature.

4. *Cirro-cumulus.*—A connected system of small roundish clouds, placed in close order, or contact.

5. *Cirro-stratus.*—A horizontal, slightly-inclined sheet, attenuated at its circumference, concave downwards, or undulated.

Lastly, says Mr. Howard, there are two modifications which exhibit a compound structure, viz.:—

6. *Cumulo-stratus.*—A cloud in which the structure of the cumulus is mixed with that of the cirro-stratus, or cirro-cumulus; the cumulus flattened at top, and overhanging its base.

7. *Nimbus.*—A dense cloud, spreading out into a crown of cirrus, and passing beneath into a shower. In addition to these general definitions, the following is an abridgement of Mr. Howard's illustrations:—

The cirrus is always the least dense, and generally the most elevated modification, sometimes covering the whole face of the sky with a thin transparent veil, and at other times forming itself into distinct groups of parallel lines, or fibres. Its height, according to Mr. Dalton, is from three to five miles above the earth's surface. It is generally found to precede wind. When formed into horizontal sheets, with streamers pointing upwards, it indicates approaching rain; with depending fringe-like fibres, it is found to precede fair weather.

The cumulus is generally of a dense structure, and appears, after a clear morning, increasing from above, where its surface is convex, and forming at its greatest magnitude a pile of irregular semicircular clouds. This takes place about the time of the greatest heat of the day, and gradually diminishes towards evening, when it sometimes perceptibly evaporates: in this case it is an indication of the finest weather.

The cirro-cumulus appears to be formed by the descent of the cirrus, the oblique denser tufts of the latter changing into the spheroidical form, when the cloud assumes the appearance of a ball of flax, with one end left flying out. The cirro-cumulus sometimes consists of distinct beds, floating at different altitudes, the clouds appearing smaller and smaller, till they are lost in the blue expanse. It is most frequent in summer, and, when permanent, affords one of the surest indications of an increasing temperature, and fine weather.

The cirro-stratus assumes various appearances, from its being frequently connected with other modifications. By itself, it is always an attenuated sheet or patch, of an uniform hazy appearance when viewed overhead, and of great apparent density towards the horizon. In this state, it gives rise to the phenomena of halos, mock-suns, &c. and indicates a depression of temperature, wind, and rain. When it alternates with cirro-cumulus, the prognostic is doubtful. It is frequently seen resting on the summit of high hills, and, in this state, has been long regarded as foreboding rainy weather.

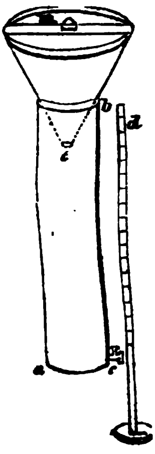
The cumulo-stratus is that fleecy cloud which is sometimes observed to settle on the summit of a cumulus, while the latter is increasing from beneath. It usually prevails in an overcast sky, and apparently without any regard to temperature, as it is found to precede either a fall of snow, or a thunder-storm. Before a storm, it is frequently to be seen in different points of the horizon, rapidly swelling to a great magnitude. Its indication is doubtful, and must be determined by the prevalence of the other modifications that accompany it.

The nimbus generally appears in the form of a dense, inverted cone of cloud, the upper part of which spreads in one continued sheet of cirrus to a great distance from where the shower is falling. When the total evaporation of the cloud takes place after the shower, it is reckoned a prognostic of fair weather. When the nimbus appears by itself, it generally moves with the wind; but when formed in the midst of cumuli, it sometimes moves in a contrary direction. This is often the case with thunder-showers.

From the hygrometer, we naturally pass to the *rain-gage.*

This useful instrument may be constructed in so simple a form, as to be accessible to every meteorological observer.

In the accompanying figure, it is seen to consist of a funnel *m*, attached to the top of a cylindrical vessel *b*. The bottom *a c*, is furnished with a stop-cock to draw off the water when full, and also to open a communication with the graduated glass tube *d*. The tube is divided into parts, so as to register the quantity of water that enters the vessel, and so proportioned, as to compensate for the difference between the sizes of the funnel and cylinder.



In fixing rain-gages, care should be taken that the rain may have free access to them, without being impeded or overshaded by any adjacent building. It may be proper also to add, that when the quantities of rain collected in them, in different places, are compared together, the instruments ought to be fixed at the same height above the ground at both places; because at different heights the quantities are always different, even in the same place. And hence, also, any register or account of rain in the gage, ought to be accompanied with a note of the height at which the instrument is placed above the ground. Dalton found the rain of a gage fifty yards high, in summer, two-thirds, and in winter, one-half as much as that of a gage below. The above ingenious experimentalist adds, that a strong funnel, made of sheet-iron, tinned and painted, with a perpendicular rim, two or three inches high, fixed horizontally in a convenient frame, with a bottle under it to receive the rain, is sufficient for this purpose.

The origin of *mists* must be sufficiently obvious to any person at all acquainted with meteorological phenomena, and we only notice the subject, to direct attention to Sir Humphrey Davy's elegant and simple theory. According to this eminent chemist, land and water are cooled after sunset in a very different manner. The impression of cooling on the land is limited to the surface, and is very slowly transmitted into the interior. Whereas, in water, the upper stratum, when cooled, descends, and has its place supplied by warmer water from below. The surface of water will, therefore, in calm and clear weather, and in temperatures above 45° Fahrenheit, be warmer than that of the contiguous land; and, consequently, the air above the land will be cooler than that above the water. When the cold air, therefore, from the land, mixes with that above the water, both of them containing their due proportion of aqueous vapour, a mist, or fog, must be the result.*

There are mists which occasionally occur of a very peculiar character. They are sometimes attended by a smell, resembling that which is occasioned by an electric spark. There must, indeed, frequently be a multiplicity of substances of various kinds floating in the air: the wind has been found to carry the farina of plants as far as thirty or forty miles, and the ashes of a volcano more than two hundred. It is only necessary that the magnitude of the particles should be exceedingly small, in order to render them incapable of falling with any given velocity; and when this velocity is very trifling, it may easily be overpowered by any accidental motions of the air. The diameter of a sphere of water, falling at the rate of one inch only in a second, ought to be one six hundred thousandth of an inch, which is about the thickness of the upper part of a soap-bubble at the instant when it bursts; but the particles of mist are incomparably larger than this, since they would otherwise be perfectly invisible as separate drops: the least particle that could be discovered by the naked eye, being such as would fall with a velocity of about a foot in a second, if the air were perfectly at rest. But it is very probable that the resistance opposed to the motion of particles so small, may be considerably greater than would be expected from a calculation derived from experiments made on a much larger scale, and their descent consequently much slower.

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* Philosophical Transactions, 1819, Part 1.

When the particles of mist are united into drops capable of descending with a considerable velocity, they constitute rain; if they are frozen during their deposition, they exhibit the appearance of a perfect crystallization, and become snow: but if the drops already formed are frozen, either by means of external cold, or on account of the great evaporation produced by a rapid descent through very dry air, they acquire the character of hail,* which is often

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* Mr. Dalton furnishes the following average statement of the number of days on which hail was observed in each succeeding month through the year.

Months.	No. of days on which hail was observed.
January	11
February	7
March	5
April	8
May	11
June	6
July	2
August	1
September	6
October	7
November	7
December	13

observed in weather much too hot for the formation of snow.

The phenomenon of *red snow* is so singular, that a few facts connected with the subject, from observations made by the Prior of the convent of Great St. Bernard, may with propriety be appended. He says that it is found at the heights of Buet, St. Bernard, Col de la Seigne, and Bonhomme; and also above and below, if masses exist large enough to remain through the summer. It is found sometimes on the glaciers. It is most abundant after strong winds from the west and south-west, and is most abundant as the summer advances, though no one has seen it fall. The Prior thinks it is earthy and ferruginous; that it is caused by particles brought by the winds, or sometimes by currents of water. It is not to be obtained before the middle of June.

Two portions of this coloured snow were furnished by the Prior to M. Peschier, who analysed them. One had an earthy appearance, and a ferruginous dirty-yellow colour: when heated, it lost a tenth of its weight, and deepened in colour. 100 parts gave

Silicious matter - - - - -	65.5
Alumine - - - - - -	6.35
Peroxide of iron - - - - -	21.35
Organized matter - - - - -	6.8
	100

The other specimen appeared like a coarse vegetable earth, in which the eye could distinguish fragments of lichen, &c. It came from a spot of red snow, above which a red tint was observed, supposed by the Prior to be caused by the decomposition of a cryptogamous plant:

this kind of snow is rare, and occurs only in small spots. When strongly heated, it gave out vegetable fumes, and 100 parts lost 40. The residuum was of a brilliant violet colour. 100 parts, on analysis, gave

Insoluble matter - - - - -	20.
Alumine - - - - - - -	4.25
Peroxide of iron - - - - -	31.25
Zinc - - - - - - - -	.5
Insoluble organized matter - - -	37.5
Soluble organized matter - - -	6.5
	100.

The instruments that are employed to ascertain the comparative temperature of various bodies, must now be examined.

The *thermometer* will in the first instance occupy our attention.

A common thermometer consists of a tube terminated at one end by a bulb, and closed at the other. The bulb and part of the tube are filled with a proper liquid, generally mercury, and a scale is applied, graduated into equal parts. Whenever this instrument is applied to bodies of the same temperature, the mercury being similarly expanded, indicates the same degree of heat.

In dividing the scale of a thermometer, the two fixed points usually resorted to, are the freezing and boiling of water, which always takes place at the same temperature, when under the same atmospheric pressure. The intermediate part of the scale is divided into any convenient number of degrees; and it is obvious, that all thermometers thus constructed, will indicate the same degree of heat when exposed to the same temperature. In the centigrade thermometer, this space is divided into 100°; the freezing of water being marked 0°, the boiling point 100°. In this country we use Fahrenheit's scale, of which the 0° is placed at 32° below the freezing of water, which, therefore, is marked 32°, and the boiling point 212°, the intermediate space being divided into 180°. Another scale is Reaumur's, the freezing point is 0°, the boiling point 80°. These are the principal thermometers used in Europe.

It may be proper to state, that the spirit of wine thermometer is usually employed for very low temperatures, as mercury may be frozen in the atmosphere;* whilst mercury, on the contrary, is best calculated for high temperatures, as its point of ebullition is little short of a red heat.

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* In the year 1780, Mr. Van Ellertein, of Vytegra, in Russia, froze quicksilver by natural cold. This occurred on the 4th of January, the thermometer being at 34° of Fahrenheit's scale. Expecting such a result, he placed three ounces of very pure quicksilver in a china teacup, covered with paper pierced full of holes. On examining it the next morning, he found the mercury solid, and looking like a piece of cast-lead, with a considerable depression in the middle. On attempting to loosen it in the cup, his knife raised shavings from it: and at length, the metal separated from the bottom of the cup in one mass. He then took it in his hand to try if it would bend: it was stiff like glue, and broke into two pieces; but his fingers immediately lost all feeling, and could scarcely be restored in an hour and a half by rubbing with snow. At eight o'clock, the thermometer stood at 57°; but by half after nine, it was risen to 40°; and then the two pieces of mercury which lay in the cup, had lost so much of their hardness, that they could no longer be broken, or cut into shavings, but resembled a thick amalgam, which, though it became fluid when pressed by the fingers, immediately afterwards resumed its original character. With the thermometer at 39, the quicksilver became fluid. The cold was never less on the 5th than 28, and by nine in the evening it had increased again to 33. This experiment, as well as those of Mr. Cavendish, seem to fix the freezing point of mercury at 39 or 40 of Fahrenheit's thermometer, which is 72° below the freezing point of water.

The principal thermometric scales in Europe are, as we have already stated, Fahrenheit's, which commences at the temperature produced by mixing snow and salt, and which is 32° below the freezing of water, so that the latter point is marked 32°, and the boiling point 212°, the intermediate space being divided into 172°; Reaumur's, in which the zero is the freezing point, and 80° the boiling point; and the centigrade, in which the space between the freezing and boiling of water is divided into 100°.

Each degree of Fahrenheit's scale is equal to 4-9ths of a degree on Reaumur's; if, therefore, the number of degrees on Fahrenheit's scale, above or below the freezing of water, be multiplied by 4, and divided by 9, the quotient will be the corresponding degree of Reaumur.

Fahrenheit. Reaumur.
68°—32°= 36 × 4=144÷9=16°.
212°—32°=180 × 4=720÷9=80°.

To reduce the degrees of Reaumur to those of Fahrenheit, they are to be multiplied by 9, and divided by 4.

Reaumur. Fahrenheit.
16° × 9=144÷4= 36+32°= 68.
80° × 9=720÷4=180+32°=212.

Every degree of Fahrenheit is equal to 5-9ths of a degree on the centigrade scale; the reduction, therefore, is as follows:

Fahrenheit. Centigrade.
212°—32=180 × 5=900÷9=100°.

Centigrade. Fahrenheit.
100 × 9=900÷5=180+32=212°.

In mercurial thermometers with a perfect vacuum above the mercury, M. Flanguergues has observed, that the freezing point has gradually risen nine-tenths of a degree, and has gone on increasing for years. He attributes this to a permanent change of form, produced by the constant pressure of the atmosphere on the bulb. He therefore recommends, that the thermometers should be made with open terminations. The same fact had been long before observed by M. Angelo Bellani, who illustrates the matter by the following experiment. "Take a mercurial thermometer, which has not been exposed for some months to temperatures near that of boiling water, and whose degrees are at least a line long, so that tenths of a degree can be easily seen. Having carefully marked the freezing point, plunge it in boiling water, and upon replacing it in melting ice, it will be found, that the freezing point has sunk 1-10th of a degree, in consequence of the expanded glass not having resumed accurately its original form."

If a bulb of a thermometer be suddenly squeezed between the finger and the thumb, the mercury will rise in the stem several degrees, and will again sink as quickly after the pressure is removed. To prevent any derangement from communication of heat, the hand may be covered with a thick glove. This is a very important fact, and it may be shown in a less exceptionable way:—let a mercurial thermometer, with a large bulb and a long stem, be first held upright, and then immediately inverted; between these two positions the column of mercury will descend through a visible space: thus proving, that a variable pressure in the atmosphere, or mercury, will produce anomalies in the thermometer.

Mr. Breguet's thermometer consists of slips of two metals, unequally expanded by heat, twisted into a spiral: to the extremity of the spiral is fixed an index, which moves round a graduated circle, pointing out the temperature. It is obvious, that when the spiral is heated, the index will move in one direction, and in another when the spiral is cooled, because it will twist or untwist itself according to the changes of temperature to which it is subjected. The two metals employed, are silver and platinum; and in order to render the extreme points more fixed, and to prevent sudden starts, a slip of gold, the expansibility of which is intermediate between that of silver and platinum, is soldered between these two metals. This thermometer is more delicate than any mercurial thermometer whatever. It is even more delicate than an air-thermometer. This spiral-thermometer, and a mercurial one, were placed together under the receiver of an air-pump. The temperature at the time of the experiment was 66.2°. The mercurial thermometer, when the air was pumped out, sunk 3.6°; but the spiral thermometer fell 41.4°, and descended to 24.8° Fahrenheit.

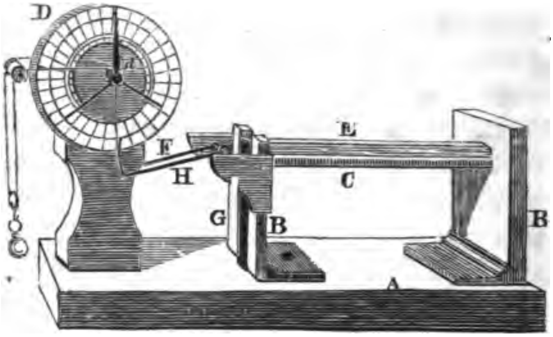
The *differential thermometer* invented by Professor Leslie, consists of two tubes, each terminating in a small bulb of similar dimensions; a small portion of dark-coloured fluid formed of sulphuric acid tinged with carmine, having previously been introduced into one of the balls. The instrument is then fixed on a stand, and furnished with a graduated scale. When the column is equally pressed in opposite directions, the fluid will point at zero, and whatever heat may be applied to the whole instrument, provided both bulbs receive it in an equal degree, the fluid must remain at rest. But if the one ball receives the slightest excess of temperature, the air which it contains will be proportionally expanded, and the column will be depressed with a force equal to the difference between the temperature of the two balls.

A *self-registering thermometer* is a most important instrument, and as such, must not be passed unnoticed. It is employed to indicate the extreme changes that occur in the temperature of the air. Dr. Rutherford employed two thermometers. The one which marks the minimum, is filled with alcohol; and the other, which indicates the maximum, is filled with quicksilver: and they are both attached to the same frame, or, what is still better, affixed to separate frames, placed nearly horizontal, or rather, elevated about five degrees, to prevent the separation of the thread of liquid. The tubes have bores from the twenty-fifth to the fifteenth part of an inch wide, and include a minute tapered or conical piece of ivory, or of white or blue enamel, about half an inch long. This mark having in either thermometer its base turned towards the bulbs, is drawn to the lowest point by the alcohol, which again freely passes it; but it is always pushed forward to the highest limit by the mercury, which afterwards leaves it.

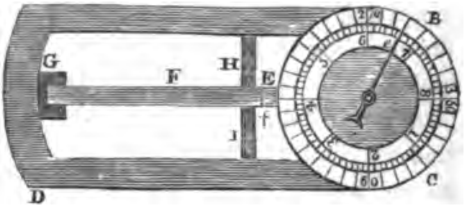
Mr. Crichton has contrived a self-registering thermometer, somewhat similar to that of M. Breguet; consisting of two oblong slips of steel and zinc, firmly fixed together by their faces; so that the greater expansion or contraction of the zinc, over those of the steel, by the same variations of temperature, causes a flexure of the compound bar. As this is secured to a board at one end, the whole flexure is exercised at the other, on the short arm of a lever index, the free extremity of which moves along a graduated arc. The instrument is originally adjusted on a good mercurial thermometer; and the movements of the arm are registered by two fine wires, which are pushed before it, and left at the maximum deviation to the right or left of the last observed position, or temperature.

The *pyrometer* is employed to indicate higher degrees of temperature than the instruments hitherto described; and although it is not essentially a meteorological instrument, its construction is much too important to be passed unnoticed.

One of the earliest instruments invented for ascertaining the amount of expansion in solid bodies, was suggested by Muschenbroeck: it was, however, liable to some serious objections; and the accompanying figure represents Mr. Ellicott's improvements on the apparatus.



This instrument is formed of a flat piece of brass A, attached to a thick piece of mahogany. Upon this plate are screwed three pieces of brass, two of which, B B, serve to support the flat iron bar C, called the standard bar. The upper part of the third piece of brass is a circle, D, about three inches in diameter, divided into three hundred and sixty equal parts, or degrees: within this circle is a moveable plate *d*, divided likewise into three hundred and sixty parts, and a small steel index hand. The bar of metal, E, upon which the experiment is to be made, is laid on the standard-bar. F, is a lever two inches and a half long, fastened to an axis, which turns in two pieces of brass, screwed to one of the supports B. To the end of this lever is fastened a chain, or silk line, which, after being wound round a small cylinder, to which the index in the brass circle, D, is fastened, passes over a pulley with a weight hung to the end of it. Upon the same axis as the lever, is placed a pulley a quarter of an inch in diameter, to which a piece of watch-chain is fastened, the other end of which is hooked to a strong spring at G, which bears against one end of the metal E. H is a lever, exactly of the same form and dimensions with the other; but the chain fastened to the pulley on its axis, is hooked to the standard bar. The line fastened to the end of this lever, after being wound round a cylinder, to which the moveable plate is fixed, passes over a small pulley, and has a weight hung to the end of it; or rather the same line, passing under a pulley, to which the weight is hung, has its other end fastened to the lever F, so that one weight serves for both levers. From this description, it will be obvious that whenever the bar E is lengthened, it gives liberty to the weight to draw the lever F upwards, by its action on the spring G; and the index will, at the same time, by means of the silk line, be carried forward in the circle; and as the bar shortens, it will return back again: the same motion will be communicated to the standard-bar. When the bar is lengthened the twentieth part of an inch, the index will be carried once round the brass circle, which is divided into three hundred and sixty degrees; and therefore, if the metal lengthens the 7200dth part of an inch, the index will move one degree. In order to make an experiment with this instrument, lay a bar of any kind of metal, as E, on the standard bar, then heat this bar to any degree of heat with a lamp, and mark the degree of its expansion, as indicated by the moveable plate; observe also the degree of expansion of the metal E, by the heat communicated to it from the standard-bar, as marked on the brass circle by the index; let the instrument stand till the whole is thoroughly cold: then removing the bar E, lay any others successively in its place, and proceed exactly as before; and thus the degrees of expansion of different metals by the same degree of heat may be estimated.



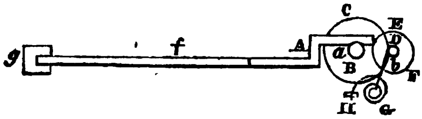
Ferguson's pyrometer indicates the expansion of metals to the 45,000dth part of an inch. The upper surface of this machine is represented in the above figure. Its frame, B C D, is made of mahogany, on which is a circle, divided into three hundred and sixty equal parts: and within that circle is another, divided into eight equal parts. If the short bar E be pushed one inch forward, (or towards the centre of the circle,) the index *e* will be turned 125 times round the circle of 360 parts or degrees. As 125 times 360 is 45,000, it is evident, that if the bar E be moved only the 45,000dth part of an inch, the index will move one degree of the circle. But, as in this pyrometer the circle is nine inches in diameter, the motion of the index is visible to half a degree, which answers to the 90,000dth part of an inch in the motion of the short bar E.

One end of a long bar of metal, F, is laid into a hollow place in a piece of iron, G, which is fixed to the frame of the machine; and the other end of this bar is laid against the end of the short bar E, over the supporting cross-bar H I: and, as the end, *f*, of the long bar is placed close against the end of the short bar, it is plain, that if F expands, it will push E forward, and turn the index *e*.

The machine stands upon four short pillars, high enough from a table, to let a spirit lamp be put on the table under the bar F; and, when that is done, the heat of the flame of the lamp expands the bar, and turns the index.

There are bars of different metals, as silver, brass, and iron, all of the same length as the bar F, for trying experiments on their various expansive powers.

The inside of this pyrometer is constructed as follows:



In the above figure, A *a* is the short bar, which moves between rollers; and, on the side *a*, it has fifteen teeth in an inch, which revolve in the leaves of a pinion, B, (twelve in number,) on whose axis is the wheel C, of one hundred teeth, which move in the ten leaves of the pinion D, furnished with a wheel E, of one hundred teeth, connected with the pinion F, of ten leaves, and on the top of this axis is placed the index-hand.

Now, as the wheels C and E have one hundred teeth each, and the pinions D and F have ten leaves each, it is plain, that when the wheel C turns once round, the pinion F, and the index on its axis, will turn one hundred times round. But, as the first pinion B has only twelve leaves, and the bar A *a*, that turns it, has fifteen teeth in an inch, which is twelve and a fourth part more, one inch motion of the bar will cause the last pinion F, to turn one hundred times round, and a fourth part of one hundred over and above, which is twenty-five. So that if A *a* be pushed one inch, F will be turned one hundred and twenty-five times round.

A silk thread is tied to the axis of the pinion D, and wound several times round it; and the other end of the thread is tied to a piece of slender watch-spring G, which is fixed in the stud H: so that as the bar *f* expands, and pushes the bar A *a* forward, the thread winds round the axle, and draws out the spring; and as the bar contracts, the spring pulls back the thread, and turns the work the contrary way, which pushes back the short bar A *a* against the long bar *f*. This spring always keeps the teeth of the wheels in contact with the leaves of the pinions, and so prevents any shake in the teeth.

In the former figure, the eight divisions of the inner circle are so many thousandth parts of an inch in the expansion or contraction of the bars; which is just one-thousandth part of an inch for each division moved over by the index.

The ingenious Mr. Wedgwood, so well known for his various improvements in the different sorts of pottery-ware, also contrived an instrument for measuring the higher degrees of heat. This was effected by reference to a distinguishing property of argillaceous bodies, namely, their diminution in bulk by fire. This diminution commences at a low red-heat, and proceeds regularly, as the heat increases, till the clay becomes vitrified. The total contraction of some clay being considerably more than one-fourth part of their entire dimensions. Some of the purest Cornish porcelain clays seem the best adapted, both for supporting the intensity, and measuring the degrees of heat. This material is prepared for use by washing it over, and, whilst in a diluted state, passing it through a fine lawn sieve: it is then dried and put up in boxes. The dry clay is then softened for use, with about two-fifths its weight of water, and formed into small pieces, in moulds of metal, six-tenths of an inch broad, with the sides exactly parallel; about four-tenths of an inch deep, and an inch long.

For measuring the diminution which they have suffered from the action of fire, another gauge is made of two pieces of brass, twenty-four inches long, divided into inches and tenths, fixed five-tenths of an inch asunder at one end, and three-tenths at the other, upon a brass plate; so that one of the thermometric pieces will just fit in the wider end. If this piece be supposed to have diminished in the fire one-fifth of its bulk, it will then pass on to half the length of the gauge; if diminished two-fifths, it will go on to the narrowest end; and in any intermediate degree of contraction, if the piece be slid along till it rests against the converging sides, the degree at which it stops will be the measure of its contraction, and consequently of the degree of heat it has undergone.

The pyrometer invented by Mr. Daniell is very simple in its construction, is easily repaired when injured, and will extend the scale of the thermometer as far as the fusing point of cast-iron. It distinctly indicates a change of about seven degrees of Fahrenheit's scale.

The instrument consists of a bar of platinum, 10½ inches long, and 0.14 of an inch in diameter. It is placed in a tube of black-lead, and the difference between the expansion of the platinum bar, and the black-lead tube, is indicated upon a circular scale, by means of a fine platinum wire, one-hundredth of an inch in diameter, which is fixed to the end of the platinum bar, and is coiled three or four times round the axis of a small wheel, fixed at the back of the circular scale. The other end of the small platinum wire is bent back, and attached to the extremity of a slight spring, which keeps the wire in a state of extension. The axis of the wheel is 0.062 of an inch in diameter, and the wheel itself is toothed, and plays in the teeth of another smaller wheel, whose diameter is one-third of the first, and which has one-third of the number of teeth. An index fastened to the axis of the small wheel, indicates the temperature on a circular scale, which is divided into 360°. Instead of passing the platinum wire round the axle of the first wheel, it has been found better in practice, to attach a short silken thread to its extremity, and pass that round, and fix it to the spring.

Of all the vital phenomena, there is none at first sight more remarkable than that which animals possess of resisting the *extremes of temperature.*

It may be observed, that the heat of the body continues at nearly the same degree, though the temperature of the atmosphere is continually varying, so that a man is able to live, and to preserve the temperature of his health, either on the burning sands of Africa, or the frozen plains of Siberia.

The alterations of temperature which the human body has been known to bear, without any fatal, or even bad effects, are not less than 400° or 500° of Fahrenheit. The natural heat of the human body, in a healthy state, is about 96° or 97°. In the West Indies, the heat of the atmosphere is often at 100°, and sometimes rises even to 130° above the temperature of the human body; notwithstanding which, a thermometer introduced beneath the tongue, stands at 96° or 97°. The inhabitants of the hot regions of Surinam support, without inconvenience, the heat of their climate. We are assured, that in Senegal, about the latitude of 17°, the thermometer in the shade generally stands at 108°, without any fatal effects to men or animals. The Russians often live in places heated by stoves to 110°; and some philosophers in this country, by way of experiment, remained a considerable time in a room, heated above the boiling point of water.

On the other hand, an equal excess of cold seems to have no greater effect in altering the degree of heat proper to animal life. Delisle has observed the temperature in Siberia 70° below the zero of Fahrenheit's scale, notwithstanding which, animals lived. Gmelin has seen the inhabitants of Jeniseisk, under the 58th degree of northern latitude, sustaining a degree of cold, which in January became so severe, that the spirit in the thermometer was 116° below the freezing point. Professor Pallas, in Siberia, and our countrymen at Hudson's Bay, have experienced a nearly similar degree of cold.

Frosts often occasion a diminished supply of water in natural springs and wells. This is sometimes erroneously accounted for, by supposing that the water freezes in the bowels of the earth. But this is a mistaken view of the matter, as the most intense cold of a Siberian winter would not freeze the ground two feet in depth; but a very moderate frost will consolidate its entire surface, and make it impervious to the air. When this happens, the water which was filtering through the ground, is arrested and kept suspended in its capillary tubes by the pressure of the air.*

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* The expansion of water during congelation, must of necessity occasion the bursting of those pipes in which it is imprisoned; and

Having seen that heat expands all bodies that are brought within the sphere of its operation, whilst the absorption of caloric produces an opposite effect; we may now proceed to examine the phenomena of aërial currents, and the instruments that are employed for ascertaining their velocity.

We may commence with air in motion, or *wind*, which is a stream or current of air; and artificial winds, on a small scale, may be observed every day, in the currents of air that occur in our houses. Smoke ascends in chimneys merely from its admixture with heated air, and if a current of air is made to pass up a chimney by means of a fire in a room, the deficiency will immediately be made good by fresh air passing through the open doors and crevices. Indeed, it is found that a double current of air prevails in

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this peculiar effect of a reduced temperature has been sometimes advantageously employed in rending masses of stone, and other purposes connected with the arts. The experiments of Colonel Williams on this subject are curious and interesting. These experiments were made in America, the climate of which was admirably adapted for the purpose; and he found that, when a bomb-shell was filled with water, and a plug driven in with a sledge-hammer, a few hours' frost would so expand the water, as to project it to a distance of four or five hundred feet. When the plug was screwed in, so as to prevent a possibility of its being expelled, the shell was rent asunder, and a thin film of congealed water invariably driven out.

A great inconvenience arises from the freezing of water in the pipes employed for hydraulic purposes, particularly in the small tubes which connect the street mains with the cisterns in the metropolis. This, however, may be readily obviated by substituting a valve in the main pipe for the present ball-cock: so that the small pipe may be drained of its contents by placing it in an inclined direction: or the same effect may be produced by dispensing with the ball-cock altogether, and the pipe will empty itself when the main ceases to furnish a supply. It will, however, be evident, that a considerable waste of water will result.

all rooms which are heated beyond the temperature of atmosphere: the light air which occupies the upper part rushing outwards, while the cold air enters beneath.*

The different winds may be reduced to three classes, viz. general, periodical, and variable winds.

The *general winds* are usually called trade-winds. They always blow nearly in the same direction. In the open seas, that is, in the Atlantic and Pacific Oceans, under the equator, the wind is found to blow almost constantly from the eastward: this wind prevails on both sides of the equator, to the latitude of 28°. To the northward of the equator, the wind is between the north and east; and the more northerly, the nearer the northern limit. To the southward of the equator, the wind is between the south and east; and the more southerly, the nearer the southern limit.

Between the parallels of 28° and 40° south lat., in that tract which extends from 30° west to 100° east long. from the meridian of London, the wind is variable, but by far the greater part between the N. W. and S. W.; so that the outward-bound East-India ships generally run down their easting on the parallel of 36° south.

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* The ventilation of rooms and buildings can only be perfectly effected, by suffering the heated and impure air to pass off through apertures in the ceiling, while fresh air, of any desired temperature, is admitted from below. Various contrivances have been resorted to, to prevent the passage of cold air from above downwards through the ventilator, which can only be completely effected by keeping the ventilating tubes at a higher temperature than the surrounding air; heating them, for instance, by steam, passing them through a fire, or placing a lamp beneath them, of sufficient dimensions to cause a strong current upwards; upon the latter principle, the gas chandelier in Covent-Garden Theatre being placed under a large funnel, which passes through the roof into the outer air, operates as a very powerful ventilator, all its own heat and smoke passing off with a large proportion of the air of the house.

Beyond the northern limit of the general wind, in the Atlantic Ocean, the westerly winds prevail, but not with any certainty of continuance.

In the Atlantic Ocean, the S. E. trade-wind extends as far as 3° north, and the N. E. trade-wind ceases at the fifth degree N. In the intermediate space are found calms, with rain, and irregular uncertain squalls, attended with thunder and lightning. But this space is shifted farther to the northward or southward, according as the sun's declination is more northerly or southerly.

Periodical winds are such as blow in a certain direction for a time; and at stated seasons change, and blow for an equal space of time from the opposite point of the compass. These may be divided into two classes: viz. *monsoons*, or winds that change annually; and land and sea breezes, or winds that change diurnally.

While the sun is to the northward of the equator, that is to say, in the months of April, May, June, July, August, and September, the wind blows from the southward, over the whole extent of the Indian Ocean: namely, between the parallels of 28° N. and 28° S. latitude, and between the eastern coast of Africa, and the meridian which passes through the western part of Japan. In the sea between Madagascar and New Holland, the S. E. wind prevails as far as the equator, when it is deflected, and blows into the Arabian Gulph, and Bay of Bengal, from the S. W. Between Madagascar and the main land of Africa, a S. S. W. wind obtains, and coincides with the S. W. wind in the Arabian Gulph. To the northward of New Holland, the S. W. wind is predominant, but varies very much among the islands; and between the peninsula of Malacca and the island of Japan, a S. S. W. prevails. All this is to be understood for the above-mentioned months.

But in the other months, October, November, December, January, February, and March, a remarkable alteration takes place. In the sea between Madagascar and New Holland, the S. E. wind extends no farther to the northward than about the tenth degree of south latitude, the other ten degrees being occupied by wind from the opposite point of the compass, or N. W.; at the same time that the winds in all the northern parts of the Indian Ocean shift round, and blow directly contrary to the course they held in the former six months.

These winds are called monsoons, or shifting trade-winds. These changes are not suddenly made. Some days before and after the change, there are calms, variable winds, and dreadful storms, attended with thunder, lightning, and rain.

On the greater part of the coasts situated between the tropics, the wind blows towards the shore in the day-time, and towards the sea in the night. These periodical winds are termed land and sea breezes, and are much affected, both in their direction and velocity, by the courses of rivers, tides, &c.

Variable winds are those which are subjected to no period, either in duration or return, and are too well known to need description.

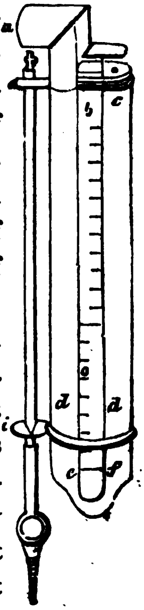
If the earth did not revolve on its axis, it is plain that the sun, being stationary over one particular spot, would rarefy the air at that spot: it would consequently ascend, by the pressure of the circum-ambient and less rarefied air, till it arrived at a region in which the air was sufficiently rare to suffer it to expand on all sides; and thus there would be produced a converging wind near the surface of the earth, and a contrary, or divergent wind in the upper region of the air. But since the earth revolves on its axis, and the sun therefore is not stationary, it must follow, that the place where the air is rarefied, will be found successively in every point of the parallel, over which the sun moves in the course of a day. And as this place continually moves to the westward, the lower air must as constantly follow it. Hence we have the origin of the general N. E. and S. E. trade-winds, which no doubt would extend over the whole of the space between the tropics, were it not for the different temperatures of the continents and islands over which the sun passes. For the surface of the earth is more readily heated than that of the sea, as the transparency of the water permits many of the rays of light to pass directly to its lower strata. The air, therefore, contiguous to the land, being more heated than that which rests upon the sea, will prevent the regularity of the effect. Thus, near the western coasts of Africa and America, the winds blow from the westward, to supply the constant rarefaction those heated lands produce.

The general N. E. and S. E. trade-winds, producing in the upper regions of the air winds in the contrary directions, seem to be the cause of the westerly winds, which are observed to prevail between the latitudes of 28° and 40°.

In accounting for the monsoons, or periodical trade-winds, it is necessary to mark the peculiar circumstances which obtain in the Indian Ocean, and which are not to be found in the Atlantic and Pacific Oceans: they seem to be these: that the ocean is bounded to the northward by shores, whose altitude does not exceed the limits of the general trade-wind, and that the general trade-wind falls on the lee-shores to the westward.

Southerly winds are most frequently accompanied with rain; but northerly and easterly, with clear, dry, and severe weather. Because southerly winds are not only warmer, proceeding from warmer climates, but also more highly electrified than the soil of the colder countries into which they flow; hence, the copious vapours they contain, are quickly deprived of part of their electricity, and thus converted into spherules of water: but the superior strata of the atmosphere under which the southern air is introduced, not being supported by air as dense as that which subsisted under them before their introduction, necessarily descend and mix with the inferior southern air; by this intermixture, they are warmed, and deprive the clouds already formed, and their vicinity, of part of their electricity. Hence proceeds their gradual attraction to each other, which terminates in the gentle showers that usually accompany this wind.

In meteorological observations, the strength and velocity of the wind are no less important than its direction; Dr. Lind's apparatus is well calculated for experimental purposes. This simple instrument consists of two glass tubes, of five or six inches in length. They are connected together like a syphon, by a small bent tube *c f*, the bore of which is 1-10th of an inch in diameter. On the upper end of the leg *d e*, there is a tube of thin brass, which is bent at a right angle, and has its mouth open towards *a*. On the other leg *c d*, is a cover, with a round hole in the upper part of it, 2-10ths of an inch in diameter. This cover and the kneed tube, are connected together by a slip of brass, which not only gives strength to the whole instrument, but also serves to hold the scale *b o*. The bent



tube and cover are fixed on with hard cement, or sealing-wax. To the same tube is soldered a piece of brass, with a round hole in it, to receive a steel axle, and at *i*, there is another piece of brass soldered to the brass hoop, which surrounds both legs of the instrument. There is a small shoulder on the spindle, upon which the instrument rests, and a nut screwed on to prevent it from being blown away. The instrument is easily turned round upon its axis by the wind, so as always to present the mouth of the bent tube towards it. The lower end of the spindle is furnished with a screw, by which it may be attached to the top of a post or stand. It is also provided with a hole at the bottom, to admit a small lever for screwing it into the wood with more facility. There is likewise a crooked tube, to be put occasionally on the mouth of the kneed tube, in order to prevent rain from being blown into the mouth of the wind-gauge when it is left out all night, or exposed in time of rain. The force, or momentum of the wind may be ascertained by the assistance of this instrument, by filling the tubes half full of water, and pushing the scale a little up or down, till the 0 of the scale, when the instrument is held up perpendicularly, be on a line with the surface of the water in both legs of the wind-gauge. The instrument being thus adjusted, hold it up perpendicularly, and turning the mouth of the kneed tube towards the wind, observe how much the water is depressed by it in one leg, and how much it is raised in the other.

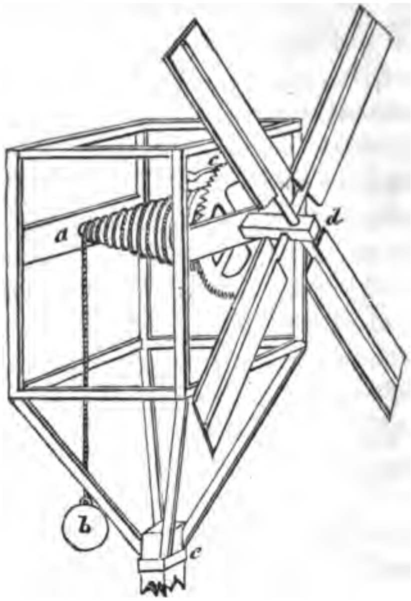
The height of the column of water sustained in the wind-gauge being given, the force of the wind, upon a foot square, is easily ascertained by the following table, and consequently on any known surface.

Height, in inches, of the water in the gauge.	Force of the wind on one square foot.	
12	62.500	
11	57.293	
10	52.083	Most violent hurricane.
9	46.875	
8	41.667	Very great hurricane.
7	36.548	Great hurricane.
6	31.750	Hurricane.
5	26.041	Very great storm.
4	20.833	Great storm.
3	15.625	Storm.
2	10.416	Very high wind.
1	5.208	High wind.
0.5	2.604	Brisk gale.
0.1	0.521	Fresh breeze.
0.05	0.260	Pleasant wind.
0.025	0.030	A gentle wind.

Mr. Martin, from a hint first suggested by Dr. Burton, contrived a wind-gauge, of the following construction.

It consists of an open frame of wood, firmly supported by the shaft or postern *e*. In the two cross pieces, is moved an horizontal axis *d a*, by means of the four sails, exposed to the wind in a proper manner. Upon this axis is fixed a cone of wood, upon which, as the sails move round, a weight *b* is raised by a string on its superficies, proceeding from the small to the largest end. Upon the great end, or base of the cone, is fastened a ratchet-wheel *c*, in the teeth of which falls the click, to prevent any retrograde motion from the depending weight.

From the structure of this machine, it is easy to understand that it may be accommodated to estimate the variable force of the wind, because the force of the weight will



continually increase as the string advances on the conical surface, by acting at a greater distance from the axis. And, therefore, if such a weight be put on the smallest part, as at *a*, which will just keep the machine in equilibrio with the weakest wind, then, as the wind becomes stronger, the weight will be raised in proportion, and the diameter of the base of the cone may be so large in comparison to that of the smaller end or axis at *a*, that the strongest wind shall but just raise the weight to the great end.

Thus, for example, let the diameter of the axis be to that of the base of the cone as 1 to 28; then if *b* be a weight of one pound at *a* on the axis, it will be equivalent to twenty-eight pounds, or a quarter of an hundred, when raised to the larger end. If, therefore, when the wind is weakest, it supports one pound on the axis, it must be twenty-eight times as strong to raise the weight to the base of the cone. Thus, if a line or scale of twenty-eight equal parts be drawn on a bar at the side of the cone, the strength of the wind will be indicated by the number, or graduation at which the string is placed.

THE SOLAR SYSTEM.

Apparent System of the Material Universe.—Planetary Bodies.—The Moon.—Eclipses.—Comets.Fixed— Stars.

When we view the vast concave above us on a clear night, and observe with attention the gradual ascent and descent of the spangled firmament that surrounds the visible horizon, the uninformed observer is at once disposed to adopt the belief of Ptolemy, and conclude that the earth is a fixed body, and that the surrounding orbs are really in motion. This very obvious phenomenon may, however, be illustrated in a more familiar way.

If we suppose a person seated in a vehicle, and that vehicle in rapid motion, it will be evident that the traveller will fancy that the fixed objects in his immediate neighbourhood are also in motion, though, of course, going in a direction the reverse of his own. This simple fact must have come within the observation of all; and yet by applying the same principle to the motions of the heavenly bodies, we shall find, that as a traveller seated in a carriage imagines that the passing objects are in motion, so do we, who are travelling at a much greater rate upon our planet or earth, suppose that the other planetary bodies partake of a motion which exists but in our own imagination.

This, then, may be considered as a brief view of the apparent motions of the planetary orbs, which has been noticed only as introductory to a more particular examination of the real motions of the heavenly bodies.

In astronomy, as well as in other sciences, the Greeks were the disciples of the Egyptians: they appear to have divided the stars into constellations, thirteen or fourteen hundred years before Christ. Newton attributes this arrangement to Chiron, and he supposes that he made the middle of the constellations correspond to the beginning of the respective signs. But until the time of the foundation of the school of Alexandria, the Greeks treated astronomy as a purely speculative science, and indulged themselves in the most frivolous conjectures respecting it. It is singular, that amidst the confusion of systems heaped upon each other, without affording the least information to the mind, it should never have occurred to men of such great talents, that the only way to become accurately acquainted with nature, was to institute experimental inquiries throughout her works.

The most ancient observations of which we are in possession, that are sufficiently accurate to be employed in astronomical calculations, are those made at Babylon, about seven hundred and nineteen years before the Christian era, of three eclipses of the moon. Ptolemy, who has transmitted them to us, employed them for determining the period of the moon's mean motion, and, therefore, had probably none more ancient on which he could depend. The Chaldeans, however, must have made a long series of observations, before they could discover their Saros, or lunar period of 6585⅓ days, or about eighteen years, at which time, as they had learnt, the place of the moon, her node, and apogee, return nearly to the same situation with respect to the earth and sun, and of course, a series of nearly similar eclipses recurs. The observations attributed to Hermes, indicate a date seven hundred years earlier than those of the Babylonians; but their authenticity appears to be extremely doubtful. The Egyptians were very early acquainted with the length of the year, as consisting of nearly three hundred and sixty-five days and a quarter, and they derived from it their Sothic period of 1460 years, containing three hundred and sixty-five days each. The accurate correspondence of the faces of their pyramids with the points of the compass, is considered as a proof of the precision of their observations.

Without, in the present case, going into the history of ancient astronomy, it may be enough to state that the sun forms one vast centre, round which the planetary bodies revolve, with their attendant satellites, or moons.

Astronomers have divided the planets into two classes. The first class they call primary, or principal planets: they are eleven in number, and consist of Mercury, Venus, the Earth, Mars, Ceres, Pallas, Juno, Vesta, Jupiter, Saturn, and the Georgium Sidus. Those of the second class are called secondary planets, or satellites.

The primary planets are such as revolve round the sun only. These are also divided into superior and inferior; those being called superior planets, whose distance from the sun is greater than that of the earth; and those inferior planets, whose distance is less than that of the earth.

The superior planets are, Mars, Ceres, Pallas, Juno, Vesta, Jupiter, Saturn, and the Georgium Sidus; these are farther from the sun than the earth, and consequently, environ the latter in their revolution. It is for this reason we see them sometimes on one side of the sun, and sometimes on the other. The inferior planets are Mercury and Venus, which are nearer the sun than the earth, and which, consequently, never environ the latter in their revolution. On this account, we see them always on the same side as the sun, and never in opposition, because the earth is never between them and the sun.

Having thus briefly examined the general arrangement of the planetary bodies, it may now be advisable to notice more particularly their size, velocity, and distance from the sun. In illustrating these important particulars, it has been found necessary to adhere closely to the data furnished in the admirable unpublished work by Francis Baily, Esq. President of the Astronomical Society.

The planet nearest to the sun, and as such, the one whose orbit round that body is least in diameter, is Mercury. The near proximity of this planet to the sun, renders it but seldom visible, and consequently, our acquaintance with it is not of a very accurate nature. According, however, to Sir Isaac Newton, the heat and light of the sun on the surface of Mercury are almost seven times as intense as on the surface of the earth in the middle of summer, and this, it may very readily be shown, is quite equal to the boiling point of Fahrenheit's thermometer; and such a degree of heat as this must evidently render Mercury uninhabitable to beings at all like those who inhabit our planet.

Mercury performs his mean sidereal revolution in 87·9692580 mean solar days, or in $87^{d}.23^{h}.15^{m}.43^{s}.9$: and his mean synodical revolution in 115.877 mean solar days.

His mean longitude, at the commencement of the present century, was in 166°.0′.48″.6.

His orbit is inclined to the plane of the ecliptic, in an angle which, at the commencement of the present century, was 7°.0′.9″,1: and which angle is subject to a small increase of 0″,1818 in a year.

The rotation on his axis is accomplished in $24^{h}\ 5^{m}.28^{s}.3$.

The inclination of its axis to that of the ecliptic is not known.

Mercury changes his phases like the moon, according to his various positions with regard to the sun and earth: but this cannot be discovered without the aid of a powerful telescope.

His true diameter, compared with that of the earth, considered as unity, is 0.398, which makes it about 3140 miles.

The proportion of light and heat, which it receives from the sun, is about 6.68 times greater than that received on the earth.

Mercury is sometimes seen to pass over the sun's disc, which can happen only when he is in his nodes, and when the earth is in the same longitude. Consequently this phenomenon, for many centuries to come, can take place only in the months of May or November. The first observation of this kind was made by Gassendi, in November, 1631; since which period they have been frequent.*

* The following is a list of all those which have happened since the above date, inclusive, and of those that will happen till the end of the present century.

1631, Nov. 6.
1644, Nov. 8.
1651, Nov. 2.
1661, May 3.
1664, Nov. 4.
1674, May 6.
1677. Nov. 7.
1690, Nov. 9.
1697, Nov. 2.
1707, May 5.
1710, Nov. 6.
1723, Nov. 9.
1736, Nov. 10.
1740, Nov. 2.
1743, Nov. 4.
1753, May 5.
1756, Nov. 6.
1769, Nov. 9.

1776, Nov. 2.
1782, Nov. 12.
1786, May 3.
1789, Nov. 5.
1799, May 7.
1802, Nov. 8.
1815, Nov. 11.
1822, Nov. 4.
*1832, May 5.
1835, Nov. 7.
*1845, May 8.
*1848, Nov. 9.
*1861, Nov. 11.
*1868, Nov. 4.
*1878, May 6.
1881, Nov. 7.
1891, May 9.
1894, Nov. 10.

Those marked with an asterisk are such future ones as will be visible in this country.

Venus is very nearly as large as the earth. Her revolution occupies about seven months, her distance from the sun being about 7-10ths of that of the earth, and her orbit nearly circular, inclined in an angle of 3°.24′ to the ecliptic. Mr. Schroeter considers her mountains as much higher than those of the earth. Her density has been estimated from the perturbations occasioned by her attraction in the motions of the other planets, and it has been supposed to be a little less than that of the earth.

The mean distance of Venus from the sun is 0.7233316; that of the earth being considered as unity. This makes her mean distance nearly sixty-eight millions of miles.

She performs her mean sidereal revolution in precisely 224.7007869 mean solar days, or in $224^{d}.16^{h}.42^{m}.8^{s},0$: and her mean synodical revolution in 583.920 mean solar days.

The rotation on her axis is accomplished in $23^{h}.21^{m}.7^{s}.2$.

Venus changes her phases like the moon, according to her various positions with respect to the sun and the earth, which causes a very considerable difference in her brilliancy.

Her true diameter, compared with that of the earth, considered as unity, is 0,975, which makes it about 7,700 miles.

A body which weighs one pound at the equator of the earth, would, if removed to the equator of Venus, weigh only 0.98 pound.

The proportion of light and heat which she receives from the sun, is about one hundred and ninety-one times greater than that received on the earth.

She is surrounded by an atmosphere, the refractive powers of which differ very little from those of the terrestrial atmosphere.

As viewed from the earth, Venus is the most brilliant of all the planets; and may sometimes be seen with the naked eye at noon-day. She is known and recognised as the morning and evening star; and never recedes far from the sun.*

Venus must have a climate far more temperate than Mercury, yet much too torrid for the existence of animals or vegetables, except in some circumpolar parts; her magnitude and diurnal rotation differ but little from those of the earth, and her year is only one-third shorter; so that her seasons, and her day and night, must greatly resemble ours. The earth, when in opposition to the sun, must be about four times as bright as Venus ever appears to us, and must, therefore, always cast a shadow; it must be frequently, and perhaps generally, visible in the day; and, together with the moon, must exhibit a very interesting object.

The *Earth* is the next planet beyond Venus in the solar system. Her distance from the sun is at a mean 95,000,000 of miles, and her annual revolution is performed in $365^{d}.5^{h}.48.^{m}49^{s}$: this is called her tropical year; but the time she takes to perform an annual revolution from any fixed star to the same again, as seen from the sun, is $365^{d}.6^{h}$.

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* Venus is sometimes seen to pass over the sun's disc, which can happen only when she is in her nodes, and when the earth is in the same longitude. Consequently this phenomenon, for many centuries to come, can take place only in the months of June or December. It is a phenomenon indeed of very rare occurrence, as may be readily seen by the following list, which contains all those transits of Venus which have occurred since that which took place in December 1639, inclusive, (the first that was ever known to have been seen by any human being,) to the end of the 21st century.

1639, Dec. 4.
1761, June 5.
1769, June 3.
1874, Dec. 8.
1882, Dec. 6.
2004, June 7.
2012, June 5.

$9^{m}.9^{s}$, which is called a sidereal year. Her rotation on her axis is performed in twenty-four hours, which is called the length of a natural day. The earth's mean diameter is 7916 miles. Her diurnal rotation being from west to east, the diurnal motion of all the heavenly bodies appears to be from east to west.

Next to the sun, the moon appears to us the most splendid of all the heavenly bodies, though she is but a satellite, or attendant, to our own planet. Her orbit is an ellipse, with the earth in one of its foci; her synodical revolution round the earth is performed in $29^{d}.12^{h}.44^{m}.3^{s}$., and with the earth she revolves round the sun in a year. Her mean diameter is about 2160 miles; it is therefore her comparative nearness to us that makes her appear so large and afford so much light. Her rotation on her axis is performed in the same time as her revolution round the earth; hence she always keeps the same side towards our planet. The phenomena of the moon's phases, and the nature of eclipses, will be fully discussed under *planetary motion.*

The next planet beyond the earth in the solar system, is *Mars*, whose mean distance from the sun is rather more than 142,000,000 of miles. The colour of this planet is a dusky red, an appearance attributed to the great density of his atmosphere, which permits only the red rays to be reflected to us. From the spots which have been observed on his disc, his rotation on his axis has been ascertained to be performed in $24^{h}.39^{m}.21^{s}$. His equatorial is to his polar diameter as 16 to 15; the true diameter being about 4100 miles.

Mars is not subject to the same limitation in his motion as Mercury or Venus, but appears sometimes very near the sun, and at other times a great distance from that luminary; sometimes rising when the sun sets, or setting when the sun rises. He sometimes appears gibbous, but never horned like the moon; a proof that his orbit includes that of the earth, and that he shines by a borrowed light. When he is opposite to the sun, or when we see him on the meridian at midnight, he is much more brilliant than in another situation, being five times nearer to us than at a conjunction.

The sun affords to Mars only about a third of the light he affords to the earth, and it has therefore been thought singular that he has not yet been discovered to have a moon; but perhaps he is compensated for this apparent want, and the light he receives may be prolonged, by the height and density of his atmosphere, which is so remarkable, that when he approaches any of the fixed stars, they change their colour, grow dim, and often become nearly invisible, though at some little distance from the body of the planet.

Mars appears to move from west to east round the earth, but his apparent motion is very unequal. When we first perceive him in the morning, separating from the sun, his motion is the most rapid; but this rapidity diminishes gradually, and ceases altogether when the planet is about 137° from the sun; then his retrograde motion commences, and increases in rapidity till he comes into opposition with the sun. It then gradually diminishes again, till the planet is within 137° of the sun; it then becomes direct, till at last the planet is lost for a time in the evening rays of that luminary.

Besides the dark spots which serve to determine the diurnal revolution of Mars, several early astronomers observed that a segment of his globe about the south pole, exceeded the rest of his disc so much in brightness, as to appear as if it were the segment of a larger globe. Maraldi informs us, that this bright spot had been taken notice of for sixty years, and was more permanent than the other spots on the planet. One part of it is brighter than the rest, and the least bright part is subject to great changes, and has sometimes disappeared. A similar brightness about the north pole was also sometimes observed, and these observations are now confirmed by Dr. Herschel, who has viewed the planet with much better instruments, and much higher magnifying powers, than any other astronomer. "The analogy, says the Doctor, "between Mars and the Earth, is by far the greatest in the whole solar system. Their diurnal motion is nearly the same; the obliquity of their respective ecliptics not very different. Of all the superior planets, the distance of Mars from the sun is by far the nearest alike to that of the earth; nor will the length of the year to Mars appear very different from what we enjoy, when compared to the surprising duration of the years of Jupiter, Saturn, and the Georgium Sidus. If then we find that the globe we inhabit has its polar region frozen and covered with mountains of ice and snow, that only partly melt when alternately exposed to the sun, I may well be permitted to surmise, that the same causes may probably have the same effect on the globe of Mars; that the bright polar spots are owing to the vivid reflection of light from frozen regions, and that the reduction of those spots is to be ascribed to their being exposed to the sun. In the year 1781, the south polar spot was extremely large, which we might well expect, as that pole had but lately been involved in a whole twelvemonth's darkness and absence from the sun; but in 1783 I found it considerably smaller than before, as it decreased considerably from the 20th of May till about the middle of September, when it seemed to be at a stand. During this last period, the south pole had already been above eight months enjoying the benefit of summer, and still continued to receive the sun-beams, though, towards the latter end, in such an oblique direction as to be but little benefited by them. On the other hand, in the year 1781, the north polar spot, which had been its twelvemonth in the sunshine, and was but lately returning into darkness, appeared small, though undoubtedly increasing in size. Its not being visible in the year 1783, is no objection to these phenomena, being owing to the position of the axis, by which it was removed out of sight."

In the interval between Mars and Jupiter, and nearly at the distance where, from a dependance on the regularity of the progression already mentioned, a number of astronomers had for some years been seeking for a primary planet; the observations of Mr. Piazzi, Dr. Olbers, and Mr. Harding, have placed four very small bodies, differing but little in their mean distance and their periodical time.

They have named them Ceres, Pallas, Vesta, and Juno.

Vesta was discovered by Dr. Olbers, on March 29, 1807; its mean distance from the sun is 2·367870; that of the earth being considered as unity.

It performs its sidereal revolution in 1325·7431 mean solar days; and its mean synodical revolution in 503·41 days.

Its mean motion in its orbit, in a mean solar day, is 16′.17″.9516: its mean motion in 365 days is consequently 99°.9′.15″,33.*

Ceres was first discovered by M. Piazzi in 1801; its mean distance from the sun is 2·767245; that of the earth being considered as unity.

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* Mr. Baily observes that the elements of this planet are not yet sufficiently determined to be depended on, and require correction from future observations. The same may be observed of the remainder of the asteroids.

It performs its mean sidereal revolution in 1681·3981 mean solar days: and its mean synodical revolution in 466·62 days.

Its orbit is inclined to the plane of the ecliptic at an angle of 10°.37′.26″,2: which, according to M. Gauss, has an annual decrease of 0″,44.

The eccentricity of its orbit is 0·078439; half the major axis being considered as unity: which, according to M. Gauss, is subject to an annual decrease of ·00000583.

The greatest equation of the centre is 8°.59′.42″.

Pallas was discovered by Dr. Olbers, in 1802: its mean distance from the sun is 2·772886; that of the earth being considered as unity.

It performs its sidereal revolution in 1686·5388 mean solar days: and its mean synodical revolution in 466·22 solar days.

Its mean motion in its orbit, in a mean solar day, is 12′.48″.3934: its mean motion in 365 days is consequently 77°,54′.25″,59.

The eccentricity of its orbit is 0·241648; half the major axis being considered as unity.

Juno was first discovered by M. Harding, on September 1, 1804: its mean distance from the sun is 2.669009; that of the sun being considered as unity.

It performs its sidereal revolution in 1592·6608 mean solar days: and its mean synodical revolution in 473·95 days.

Its mean motion in its orbit, in a mean solar day, is 13′.32″.9304: its mean motion in 365 days is consequently 82°.25′.19″,1.

Its orbit is inclined to the plane of the ecliptic, in an angle of 13°.4′.9″,7.

Jupiter is one of the most beautiful planets in our system. Its mean distance from the sun is above 485,000,000 of miles.

His orbit is inclined to the plane of the ecliptic, in an angle which, at the commencement of the present century, was 1°.18′.51″,3 ; and which angle is subject to a small decrease of about 0′,226 in a year.

The rotation on his axis is performed in 9^{h}.55^{m}.49^{s},7.

The inclination of his axis to that of the ecliptic is 3°.5′.30″.

His apparent diameter, (measured equatorially,) at his mean distance from the earth, is 36″,74. At its conjunction it is sometimes only 30″,0; but it increases as the planet approaches its opposition, when it sometimes amounts to 45′,88.

His true diameter, compared with that of the earth considered as unity, is 10·860, which makes it near 90,000 miles. The axis of the poles is to his equatorial diameter, as 167 to 177.

A body which weighs one pound at the equator of the earth, would, if removed to the equator of Jupiter, weigh 2·716 pounds. But this must be diminished about a ninth part, on account of the centrifugal force due to each planet.

The proportion of light and heat which he receives from the sun is ·037; that received by the earth being considered as unity.

Almost every person is sufficiently acquainted with the telescopic appearance of Jupiter, to know that its surface is remarkable for being always covered with a number of belts, or stripes, of various shades. These appearances differ much at different times, and even at the same time in telescopes of different powers. Usually, these belts seem to be of an uniform tint; but, in very favourable weather, they sometimes appear to consist of a number of curved lines, like the strokes of an engraving.

These belts were first observed at Naples, by Zuppi and Bartoli, two Jesuits; and about the year 1660 they were noticed by Campani, with refracting telescopes of his own construction, and not much inferior in distinctness to those of the present day; the great modern improvement in refracting telescopes consisting rather in the reduction of their size, than in the increase of their magnifying power.

Jupiter is accompanied by four satellites, which were discovered by Galileo, the 8th of January, 1610. He at first took them for telescopic fixed stars; but continued observation soon convinced him that they really accompanied the planet. The relative situation of these small bodies changes at every instant: they oscillate on each side the planet, and it is by the extent of these oscillations that the ranks of these satellites is determined; that being called the first satellite, whose oscillation is the least. They are sometimes seen to pass over the disc of the planet, and project a shadow in the form of a well-defined black spot, which then describes a chord of this disc.

The shadow which Jupiter himself projects behind him, relative to the sun, gives rise to another phenomenon of considerable importance. For the satellites frequently disappear, or are eclipsed in that shadow, although they appear, with respect to us, to be at a distance from the disc of the planet. These eclipses are similar in principle to lunar eclipses, which will presently be described; and vary in duration according to the relative position of the bodies with respect to the sun.

In the following table are given the mean sidereal revolution of the satellites in mean solar days; together with their mean distances from Jupiter, the semi-diameter of that planet's equator being considered as unity; and likewise their masses, compared with that of Jupiter, considered also as unity.

Sat.	Sidereal Revolution.		Mean distance.	Mass.
1	1.18.28	1.769137788148	6.04853	·0000173281
2	3.13.14	3.551810117849	9.62347	·0000232355
3	7. 3.43	7.154552783970	15.35024	·0000884972
4	16.16.32	16.688769707084	26.99835	·0000426591

First satellite. The plane of the orbit of this satellite coincides nearly with the plane of the equator of Jupiter; the inclination of which, to the orbit of the planet, is 3°.5′.30″. Its eccentricity is insensible.

Second satellite. The eccentricity of the orbit of this satellite is also insensible. The inclination of its orbit to that of its primary is variable; as well as the position of its nodes. These variations are represented nearly, by supposing the orbit of the satellite inclined 27′,49″,2 to the equator of Jupiter; and by giving the nodes a retrograde motion on this plane, so as to make a revolution in thirty Julian years.

Third satellite. This satellite has a little eccentricity, which is subject to a very sensible variation. Towards the end of the century before the last, the equator of the centre was at its maximum, and was then as much as 13′.16″,4. It afterwards diminished, and was at its minimum about the year 1777, when it was only 5′.7″,5. The line of the apsides has a direct, but variable motion. The inclination of its orbit, to that of Jupiter, and the position of its nodes, are also variable. These variations may be represented nearly by supposing the orbit inclined 12′.20″ to the equator of Jupiter; and by giving the nodes a retrograde motion on this plane, so as to make a revolution in one hundred and forty-two Julian years.

Fourth satellite. The eccentricity of this satellite is greater than that of the other three. The line of the apsides has an annual and direct motion of 42′.58″,7. The place of the nodes has a direct annual motion on the orbit of the planet, of 4′.15″,3. The inclination of the orbit to that of Jupiter is about 2°.58′.48.″ It is in consequence of this great inclination that this satellite frequently passes behind the planet, with respect to the sun, without being eclipsed. Since the middle of the last century, the inclination of the orbit has increased, and the motion of the nodes has diminished very perceptibly.

Saturn is about 890,000,000 of miles from the sun.

His orbit is inclined to the plane of the ecliptic in an angle which, at the commencement of the present century, was 2°.29′.35″,7; and which angle is subject to a small decrease of 0″,155 in a year.

His ascending node was, at the commencement of the present century, in 111°.56′.37″,4; having a motion to the westward, every year, of 19″,4. But, when referred to the ecliptic, the place of the node will (on account of the precession of the equinoxes) fall more to the eastward, by 30″,7 in a year.

The rotation on his axis is performed in $10^{h}.29^{m}.16^{s},8$.

The inclination of his axis to that of the ecliptic is 30°.19′.

A body which weighs one pound at the equator of the earth, would, if removed to the equator of Saturn, weigh 1·01 pounds.

The proportion of light and heat which it receives from the sun is about ·0011; that received by the earth being considered as unity.

He is sometimes marked by zones or belts, which are probably obscurations in the atmosphere.

Saturn is accompanied by seven satellites, and also surrounded with a double ring.*

The ring of Saturn casts a deep shadow upon the planet. It is sharply defined both in its inner and outer edge, and appears to be more luminous than Saturn himself. Hence Dr. Herschel has concluded, that it is not any shining fluid, or aurora borealis, as some have concluded, but a solid body, equal in density to the planet. The Doctor is also of opinion, that the edge of the ring is not flat, but of a spherical, or rather of a spheriodal form.

In examining the plane of the ring with a powerful telescope, he perceived, near the extremity of its arms, several lucid or protuberant points, which seemed to adhere to the ring. At first, he imagined them to be satellites; but he afterwards found, upon careful examination, that none of the satellites could exhibit such an appearance; and he therefore concluded, that these lucid points adhered to the ring, and that the variation in their position arose from a rotation of the ring round its axis, which he found to be performed in $10^h.32'.15^s,4$. This result is very remarkable; for if we conceive a satellite moving round Saturn, and having for its orbit the mean circumference of the ring, and if we calculate, according to the second law of Kepler, its sidereal revolution, we shall find that the duration of its revolution is nearly equal to the revolution of the ring. According to Dr. Robison, the inner edge of Saturn's ring should revolve in $11^h.16^m$, and the outer edge in $17^h.10^m$. Schroeter seems to doubt of the rotation of the ring.

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* Maupertius, in his "Discours sur la Figure des Astres," maintained, that this luminous girdle was the tail of a comet, which the attraction of Saturn had compelled to circulate round the planet. Mairan asserted that the diameter of the planet was originally equal to the diameter of its outer ring, and, that by some unknown cause, the exterior shell of Saturn was broken to pieces, which were attracted by his body; but the equatorial parts of the exterior shell remained entire, and thus formed a ring about the planet. Buffon imagined that the ring must be a part of the equator which had been detached by the excess of centrifugal force. Without, however, discussing these chimerical hypotheses, it may be sufficient to observe, that we may as well attempt to account for the formation of these satellites, as of the ring of Saturn; that none of them seem to have been the effect of any accidental cause, and that the most rational solution of the difficulty, is to suppose, that when Saturn was created and launched into the heavens, he was at the same instant encircled with a luminous ring, to answer some important purpose, which astronomers have not yet had the sagacity to discover.

The double ring consists of two concentric rings, detached from each other, and from the body of the planet, the innermost of which is nearly thrice as broad as the outermost. The following are the dimensions of this luminous zone, as determined by Dr. Herschel. (See Philosophical Transactions, 1792, part 1.)

	Miles.
Inside diameter of the interior ring .	146,345
Outside diameter of the interior ring .	184,393
Inside diameter of the exterior ring .	190,248
Outside diameter of the exterior ring .	214,883
Breadth of the interior ring . . .	20,000
Breadth of the exterior ring . .	7,200
Breadth of the dark space between the two rings	2,839
Diameter of the ring, the orbit of the earth being 1, ...	26,8914
Angle which it subtends, when seen at the mean distance of the planet .	$7'.25''.332$

The last of the planetary bodies that remain to be described; was discovered to form a part of our system, by Sir William Herschel, in 1781, who gave it the name of the *Georgium Sidus*, in honour of his Royal Patron.* Its mean distance from the sun is 19·182390; that of the earth being considered as unity. This makes his mean distance upwards of 1,800,000,000 of miles.

The mean motion in its orbit, in a mean solar day, is 0°.0117695, or 42′,37. His mean motion in 365 days is 4°.295876, or 4°.17′.45″,16.

His orbit is inclined to the plane of the ecliptic in an angle of 46′.28″,44.

His apparent diameter, even at the time of his opposition, is scarcely 4″.0.

The proportion of light and heat which it receives from the sun, is about ·003; that received by the earth being considered as unity.

From the Georgium planet the sun must be seen but as a little star, not one hundred and fiftieth part as bright as he appears to us. The axis of this planet being probably near to the plane of its ecliptic, it must be directed twice in the year towards the sun, and the limit of illumination must approach to the equator, so that almost every place on his surface must sometimes remain for a great number of diurnal revolutions, in light and in darkness; the most moderate climates having one night, in their long year, equal in duration, at least, to several of our years: and it must be confessed that this planet would afford but a comfortless habitation to those accustomed to our summer sunshine, even if it were possible to colonise it.

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* Mr. Baily states that this star, under the name of "Uranus," was observed as far back as 1690. It was seen three times by Flamsteed, once by Bradley, once by Mayer, and eleven times by Lemonnier, not one of whom suspected it to be a planet. That brilliant discovery was reserved for Herschel.

These ten planetary bodies are the only ones hitherto discovered, which have any title to be considered as primary planets, that is, as bodies revolving round the sun, in orbits so nearly circular as to remain always within the reach of our observation. It has been conjectured that the number of planets may in reality be much greater; that not only many small, and perhaps invisible bodies may be revolving in the intervals of the planets with which we are acquainted, but that larger bodies also may belong to our system, which never approach within such a distance as to be seen by us.

In order to retain in memory a general idea of the proportional distances of the primary planets from the sun, we may call that of the Earth 10, and that of Saturn 100; the distance of Mercury will then be 4, to which we must add 3 for Venus, making 7; twice 3, or 6, for the Earth, making 10; twice 6, or 12 for Mars, making 16; twice 12, or 24, making 28, for the three small planets, Juno, Pallas, and Ceres; twice 24, or 48, making 52 for Jupiter; twice 48, or 96, for Saturn, making 100; and twice 96, or 192, making 196 for the Georgium planet; and these sums will represent the distances without any material exception, in the nearest integer numbers.

The Sun, which forms so important a part of our system, must be briefly examined, preparatory to a notice of Dr. Herschel's peculiar views relative to solar light and heat.

This brilliant luminary revolves on its axis in about twenty-five days ten hours, from west to east; that is, supposing the order of the signs to be known, and a point in the sun to be opposite Aries, it moves towards Taurus. All the rotations of the different bodies, which compose the solar system, as far as they have been ascertained, are in the same direction. The time and direction of the sun's rotation is ascertained by the change in the situation of the spots, which are usually visible on his disc. The spots are frequently observed to appear and disappear, and they are in the mean time liable to great variations; but are generally found about the same points of the sun's surface.

In 1788, Mr. King published a dissertation on the Sun, in which he states, that the real body of that luminary is less than its apparent diameter: that we never discern the real body of the sun itself, except when we behold the spots: that the sun itself is inhabited as well as the earth and planets, and is not necessarily subject to burning heat; and that there is no violent elementary heat existing in the rays of the sun, but that they produce heat only when they come in contact with the planetary bodies.

Doctor Herschel also considered the Sun to be a magnificent habitable globe, surrounded by a double set of clouds; those which are nearest its opaque body being less bright and more closely connected together than those of the upper stratum; which he concluded from the luminous apparent globe it exhibits. This luminous external matter, he observes, is neither a liquid nor an elastic fluid of an atmospheric nature; for in either of these two cases it would not admit of any chasms or openings. Therefore, it must be concluded that this shining matter exists in the manner of empyreal, luminous, or phosphoric clouds, residing in the higher regions of the solar atmosphere. The Doctor then is of opinion that the spots are only accidental openings between the luminous clouds, through which we behold the opaque body of the sun, or the inferior less luminous clouds; hence, the spots appear of different shades. The Doctor rejected the terms maculæ, faculæ, luculi, and others previously in use, and substituted the following, as better adapted to express what he considered the true phenomena of the sun.

" *Openings*, are those places where, by the accidental removal of the luminous clouds of the sun, its own solid body may be seen ; and this not being lucid, the openings through which we see it, may, by a common telescope, be mistaken for mere black spots, or their nuclei.

Shallows, are extensive and level depressions of the luminous solar clouds, generally surrounding the openings to a considerable distance. As they are less luminous than the rest of the sun, they seem to have some distant, though very imperfect resemblance to penumbræ, which might occasion their having been called so formerly.

Ridges, are bright elevations of luminous matter, extended in rows of an irregular arrangement.

Nodules, are also bright elevations of luminous matter, but confined to a small space. These nodules and ridges correspond to what have hitherto been called faculæ and luculi.

Corrugations, he applies to that very particular and remarkable unevenness, ruggedness, or asperity, which is peculiar to the luminous solar clouds, and extends all over the surface of the globe of the sun. As the depressed parts of the corrugations are less luminous than the elevated ones, the disc of the sun has an appearance which may be called mottled.

Indentations, are the depressed or low parts of the corrugations ; they also extend over the whole surface of the luminous solar clouds.

Pores, are very small holes or openings, about the middle of the indentations."

As Dr. H. considered the solar clouds to consist rather of a flame than a liquid substance, he attributed the spots to the emission of an aëriform fluid, not yet in combustion, which displaces the general luminous atmosphere, and which is afterwards to serve as fuel for supporting the process: hence he supposed the appearance of copious spots to be indicative of the approach of warm seasons on the surface of the earth; a theory which he has attempted to maintain by historical evidence. The shallows he considered as parts of an inferior stratum of opaque clouds, capable of protecting the immediate surface of the sun from the excessive heat produced by combustion in the superior stratum, and probably of rendering this stupendous world fit for animated existence. In general, more or less of the real body of the sun is supposed to be visible through its lucid atmosphere, where its substance is not very intense, or where it is removed by the varying circumstances of the combustion. As some of the spots appear below the surface of the shining fluid, it may be presumed that they show us the lower parts of the sun's surface; and as other spots appear above the shining fluid, it is equally reasonable to conclude that they are the solar mountains. The former kind of spots are very variable in situation, and it is clear, that if we have the true theory of the sun before us, they may never occur twice precisely at the same place. The spots attributed to the projection of the solar mountains, are fixed with respect to the sun's surface, and are those by which the sun's rotation on his axis has been determined. Dr. Herschel, taking into consideration the great attraction exerted by the sun upon bodies placed at its surface, and the slow revolution it has about its axis, thought that the solar mountains might be more than three hundred miles high, and yet stand very firmly.

Dr. Young, in opposition to the theory of Dr. Herschel, argues, that if we inquire into the intensity of the heat which must necessarily exist wherever this combustion is performed, we shall soon be convinced that no clouds, however dense, could impede its rapid transmission to the parts below: besides, the diameter of the sun is one hundred and eleven times as great as that of the earth, and at its surface, a heavy body would fall through no less than four hundred and fifty feet in a single second; so that if every other circumstance permitted human beings to reside on it, their own weight would present an insuperable difficulty, since it would become thirty times as great as upon the surface of the earth, and a man of moderate size would weigh about two tons.

The *periods* and *velocities* of the planets, or the time in which they perform their courses, are found to preserve the most perfect harmony with their distances from the sun, and with one another. The nearer each planet is to the sun, the quicker is its motion, and its period the shorter. The great law they observe, may be thus briefly stated: the squares of their periodical times are as the cubes of their distances from the centres of their orbits.

We are indebted for a knowledge of this law to the sagacity of Kepler, who found it to obtain in all the primary planets; as astronomers have since found it also to do in the secondary ones.

Kepler deduced this law merely from observation, and comparison of the several distances of the planets with their periods: the credit of investigating it from physical principles is due to Sir Isaac Newton, who demonstrated, that such a law was inevitable.

When a body is retained in a circular orbit, by a force directed to its centre, its velocity is everywhere equal to that which it would acquire, in falling, by means of the same force, if uniform, through half the radius, that is, through one-fourth of the diameter. We may in some measure demonstrate the truth of this proposition by means of the *whirling-table*: an apparatus which is arranged on purpose for exhibiting the properties of central forces, although it is more calculated for showing their comparative, than their absolute magnitude; for, accordingly as we place the string on the pulleys, the two horizontal arms may be made to revolve either with equal velocities, or one twice as fast as the other. The sliding stages, which may be placed at different distances from the centres, and which are made to move along the arms with as little friction as possible, are in a certain proportion to the weights, which are to be raised, by means of threads passing over the pulleys in the centres, as soon as the centrifugal forces of the stages with their weights are sufficiently great; and the experiment is to be so arranged, that when the velocity, having been gradually increased, produces a sufficient centrifugal force, both stages may raise their weights, and fly off at the same instant. But, for the experiment just described, one of the stages only is required, and the time of revolution may be measured by a half-second pendulum. We may make the force, or the weight to be raised, equal to the weight of the revolving body, and we shall find that this body will fly off when its velocity becomes equal to that which would be acquired by any heavy body in falling through a height equal to half the distance from the centre, and as much greater as is sufficient for overcoming the friction of the machine.

The whirling-table is a convenient auxiliary for experimentally elucidating a variety of curious phenomena, connected with the form and motions of the planetary bodies; and the author employs the following modification of the apparatus, for illustrating the form of the earth. A large glass globe, partly filled with coloured water, is attached to the axis of the table, in the centre of which is placed a lighted taper. On making the globe revolve rapidly, the coloured water occupies the equator of the glass, and forms a fluid wall completely round the burning body.

It having thus been shown that the Earth must of necessity be protuberant in its equatorial direction, another proof of this fact may now be adduced, namely: that a pendulum, calculated to swing seconds at the poles, or in a high latitude, will not swing seconds at the equator, unless it be shortened;* therefore, as a pendulum swings by the power of gravity, that power is rather less at the equator than at the poles; partly on account of the greater distance of those parts from the equator, and partly from their greater centrifugal force, which tends to throw every thing in a tangent from its surface.† If

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* The length of a pendulum to vibrate seconds at Unst, is 39·17146. But in the neighbourhood of London, only 39·13929. Vide Captain Kater in Transactions of the Royal Society, vol. cix. p. 416.

† The centre of gravity of any mass of matter, is that point about which its parts exactly balance each other. Hence, if a body is suspended by this point, it will rest in any position in which it may be put, and whatever supports the weight at that point, bears the weight of the whole body. If a line be drawn from the centre of gravity of a body, perpendicular to the horizon, it is called the line of direction, and if this fall within the base, the body will remain stable; when, however, it falls without the base, the body must fall.

In the equilibrium of animals, many circumstances occur illustrative of the nature of gravity. When a person stands on one foot, and leans forward in the attitude which is usually exhibited in the statues of Mercury, the other foot is elevated behind, in order to bring back the centre of gravity, so as to be vertically over some part of the foot on which he stands. But, in the event of any want of precision in performing this operation, or from the narrowness of the base, it is the diurnal motion of the earth were to cease, its centrifugal force would of course be destroyed at the same time; in which case, the water it supports, would immediately retire, in order to restore the perfectly globular form of the earth, and would overwhelm the polar regions.

The mensuration of the Earth has been effected by various mathematicians. Mr. Richard Norwood, in the year 1635, took the sun's altitude when it was in the summer solstice, both at London and York, with a sextant of five feet radius; and by that means found the difference of latitude between these two cities to be two degrees and twenty-eight minutes. He then measured their distance in as exact a manner as possible; and having taken into the account all the windings of the road, with the ascents and descents, he reduced it to an arc of the meridian, and found it to contain 12,849 chains; and this distance being compared with the difference of latitude, gave him 5209 chains to a degree, or about 57,300 French fathoms or toises. This method requires no explanation, if the two places are considered as lying under the same meridian, which, indeed, is nearly the case. The same operation may also be easily performed by trigonometry, when the two places lie under different meridians; for if we measure the distance of any two objects, and take the angles which each of them makes with a third, the triangle formed by the three objects will become known; so that the two

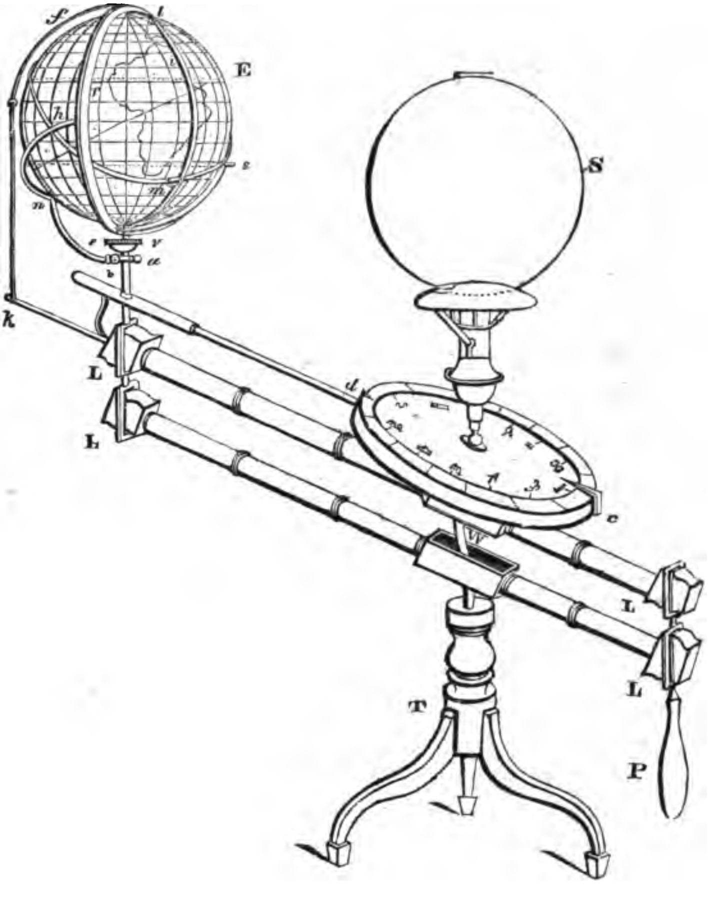
often found necessary to use muscular exertion, in order to bring the point of support to that side towards which the operator is beginning to fall. When elevated on the point of the toe, the base is still more contracted, and the body never remains at rest, but by a succession of actions of this kind, sometimes too minute to be visible, it is kept in a state of perpetual vibration, without ever attaining such a position as would ensure positive stability; and by this means, aided by habit, the arts of rope-dancers, and balancers, are acquired.

sides may be as accurately determined by calculation, as if they had been actually measured in the same manner as the first. And by making either of these sides the base of a new triangle, the distances of other objects may be found by trigonometry as before; and thus, by a series of triangles connected together at their bases, we might measure the whole circumference of the Earth. But this would be an enterprise as useless as it is laborious; for, since we know the relation which any part of a circle bears to the entire circumference, the measure of a few degrees, or even of one single degree, will give the measure of the whole. But by applying the telescope to the quadrant, and furnishing it with a micrometer, we are enabled to correct a great many inaccuracies attending this kind of mensuration.

The Academy of Sciences at Paris, perceiving from these considerations the necessity of a new measure of the Earth, represented the execution of it as a measure of national honour and importance. M. Picard was the person employed to perform this business. He began by measuring the distance between Villejuif and Juvisy; and this base, which he found to be 5663 fathoms, was that to which he referred all his calculations. He next placed himself at Juvisy, and by directing the telescopic sights of his quadrant, the one to the windmill at Villejuif, and the other to the spire of the church at Brie, he measured the angle subtended by these two objects. Leaving that station, he removed to Villejuif, and, by measuring the angle between Juvisy and Brie, the distance between Villejuif and Brie was found by calculation to be 11,012 fathoms. This distance he made a new base, and by forming a second triangle between Brie, Villejuif, and Monthleri, he found the distance, in like manner, between Brie and Monthleri, to be 13,121 fathoms. He then formed a third triangle between Monthleri, Brie, and Monjay; a fourth between Monthleri, Brie, and Malvoisine; and a fifth between Monthleri, Monjay, and Mareil; and from all these measures, the distance between Mareil and Malvoisine was found to be 31,897 French fathoms. In a similar manner, by means of thirteen triangles, he proceeded as far as Sourdon, near Amiens, and found the distance between Sourdon and Malvoisine to be 68,430 fathoms. But as calculations are less subject to errors than mechanical operations, Mons. Picard, in order to avoid every inaccuracy of this kind, took a new base near Sourdon, and found its length, both from a continuation of his trigonometrical operations, and from an actual mensuration; and as these exactly agreed, he could no longer doubt of the truth of his former calculations. This part of his project being finished, he had now to reduce the distance between Sourdon and Malvoisine to an arc of the meridian. Having obtained this terrestrial distance to a great degree of accuracy, he had only to find the celestial arc which corresponded with it. This he did by observing the meridian distances of the same star, both from the zenith of Sourdon and Malvoisine, and taking their difference; and as this difference, which he found to be one degree eleven minutes and fifty-seven seconds, answered to a distance of 68,430 fathoms upon the earth, he concluded, by the rule of proportion, that the length of a degree must be 57,064 fathoms. But having connected Amiens to his series of triangles, and finding from this new measure, that a degree would be 57,057 fathoms, he took a mean between the two, and fixed his degree at 57,060, or about sixty-nine and a half English miles.

The surveys were all taken upon a supposition, that the Earth was a perfect sphere; but the truth of this doctrine was soon called in question as the science advanced. Newton and Huygens had shown, from the known laws of gravitation, that the true figure of the Earth must be that of an oblate spheroid, flattened at the poles, and protuberant at the equator. Cassini, on the other hand, depending more upon the accuracy of his measures, than upon deductions drawn from theoretical reasoning, asserted it to be that of a prolate spheroid, flattened at the equator, and protuberant at the poles. To decide this important question, which had now become a national dispute, it was ordered by the French king, that a degree should be measured, both at the equator and polar circle, so that from a comparison of these with that in France, the true figure of the Earth might be determined in as exact a manner as possible. For this purpose, Mess. Maupertuis, Clairaut, Camus, Le Monnier, and Outhier, were sent to the North of Europe to measure the remotest degree they could reach; and Messrs. Godin, Bouger, and La Condamine, to Peru, in South America, to measure a degree near the equator. The first of these mathematicians commenced their operations at Tornea, near the Gulph of Bothnia, on the 8th of July, 1736, and finished them about the beginning of June, 1737. M. Maupertuis, soon after their return to France, published an exact account of the survey. The result of this measurement was found to be, that an arc of the meridian contained between the parallels of Tornea and Kittis, was equal to 55,023½ fathoms. And as the magnitude of this arc was found, by means of the zenith distances of certain fixed stars, to be $57'28\frac{2}{3}''$, it was determined, after proper corrections, that the true length of a degree of the meridian, which cuts the polar circle, is 57,422 fathoms. Those who were sent to Peru, in South America, had still greater difficulties to encounter than their friends in Lapland, and were a longer time employed in their operations. They set out upon their expedition about a twelvemonth before the former, and did not finish their survey till the year 1741. The province of Quito was the place determined on as the most proper for their purpose. Here they measured an arc of the meridian, of three degrees seven minutes and one second, and found it to contain 176,950 fathoms; which being reduced to the level of the sea, and properly corrected, the first degree of the meridian from the equator was found to be equal to 56,753 fathoms. These measures afford a complete demonstration that the Earth is flattened at the poles, and protuberant at the equator. For had the figure of it been a complete globe, as was formerly imagined, a degree of the meridian, in every latitude, would have been found the same; and had the figure been that which was given to it by Cassini, a degree at the polar circle would have been less than a degree at the equator.

In explaining the phenomena of the Seasons, which result from the motion of our planet, the teacher usually has recourse to an orrery, or tellurian; but the large orreries that are generally employed for the illustration of planetary motion, though well calculated for scenic effect, are of but little use in solving the simplest problems in practical astronomy. But a very ingenious apparatus has been contrived by Mr. Christie, which materially assists in the elucidation of this science. It is represented in the accompanying engraving, and consists of a lamp covered by a hollow sphere of ground-glass, S, representing the sun, round which a terrestrial globe, E, moves in a circle, whose plane makes with the horizon an angle of 23½°, two parallel levers, L L, L L, supporting the globe, and its counterpoise, P, an horizon, *h h*, and a meridian, *i m*,



turning with it on its axis, a terminator, *t r*, distinguishing the parts of the earth enlightened from those in darkness, and a claw-feet pillar or stand, T, supporting the whole.

The top of the stand is furnished with a piece of strong steel wire, W, bent 23½° from the perpendicular, corresponding with the inclination of the earth's axis to the plane of its orbit. On the bent part of the wire is fitted a brass collar, from the opposite sides of which two points extend about an inch; these points move in centres fixed in the upper lever; and this motion permits the same side of the lever to continue upwards while its ends are alternately elevated and depressed by the motion of the collar on the bent wire. The lower lever moves freely on the wire immediately under the bent part. The levers are connected at their ends by two pieces of brass, each piece having two square holes in it to admit the ends of the levers. Into the opposite sides of each hole are screwed two steel points, which move in centres, permitting the connecting pieces to continue perpendicular while they are elevated and depressed with the ends of the levers. On the top of the piece connecting the long ends is screwed a brass tube, *a b*, containing the axis of a terrestrial globe, resting on a conical point, *b*. On the lower end of the other connecting piece is screwed a leaden weight, which balances the globe, and preserves the parallelism of its axis during its annual motion. On the top of the bent wire is fixed a board, *d c*, on which are delineated the signs of the zodiac, days of the month, &c.; the board declines 23½° from the level, representing a portion of the plane of the earth's orbit, and a pointer, *c*, from the brass collar moves along the circles of signs and months, showing the sun's place or day of the month, corresponding with any position of the globe, or the position of the globe corresponding with any place of the sun or day of the month. A silk line extends round the circumference of this board, and round a pulley on the axis of the globe, to produce the diurnal motion; the line is conveyed from the board to the axis through a brass tube, *b d*, and after passing the pulley on the axis, it is carried round another pulley, (at *b*) which is fixed to the end of the upper lever, and preserves an equal tension on the line. Into the board immediately over the centre of motion of the levers, is screwed a stem supporting a lamp, with its ground glass cover.

The remaining parts, viz. the hour-circle, the meridian, the horizon, and the terminator, are more immediately connected with the globe. The hour-circle, *e o*, is fitted on the axis below the globe, sufficiently stiff to preserve its adjustment, when set to the meridian of any place. The meridian is a ring of brass attached to the poles, with its flat surface towards the globe; one semicircle of it is divided into degrees, and numbered from the equator towards the poles, for finding the latitudes of places, declination of the sun, &c. The horizon is a thin slip of brass, one end of which fits into a socket fixed on the other: it is attached to a wire which moves up or down with it in a groove near the edge of the meridian, representing at pleasure the rational horizon of any place; and it is divided into degrees and points of the compass, for finding the sun's azimuth, amplitude, &c.; it is necessary to separate the ends of the horizon when it is changed from N. to S. or from S. to N. latitude. Both meridian and horizon are turned with the globe on its axis, so that, when they are adjusted to the latitude and longitude of any place, they retain their adjustment till an alteration is required: in the pole of the horizon a point, *i*, is fixed on the wire, showing the zenith, to which a quadrant of altitude is occasionally attached. The terminator is sufficiently large to permit the globe with the other circles to turn within it; this circle is made a little concave, to reflect light on those parts which receive but little of the direct light, and to mark more distinctly the difference between the light and dark hemispheres: it is supported by two pivots, (one of which is seen at *r*,) fixed in its opposite sides even with the equator; these pivots are fitted into the ends of a strong semicircular wire, *r n*, which is supported behind the globe by a very strong piece of bent wire, *n a*, extending from the brass tube containing the axis: and the lower part of the terminator is cut to permit its passing the axis. From it a circular wire, *o s*, extends 90° upwards, on the top of which a point, *s*, is fixed, representing a central ray from the sun: this point shows the sun's declination, azimuth, amplitude, altitude, and the place where he is vertical at a given time: from the top a similar wire, *f g*, extends 90° downwards behind the globe, where it is attached by a vertical piece, *g k*, to the upper lever produced; the lower end of the vertical wire is the same distance from the piece connecting the levers as its upper end is from the centre of the globe; thus forming a kind of parallelogram, which in some positions of the globe takes the form of a rectangle, and in others that of a rhomboid. This contrivance preserves the face of the terminator constantly towards the lamp, and alternately exposes to its light the north and south poles during its annual motion.

If we commence in the summer months, we shall find the north pole of the Earth inclined to the Sun, and it will be evident that a larger proportion of this end of the globe is illuminated than of the opposite end. In this season then, the days will be longer than the nights; but if we still preserve the Earth's poles in the same direction, and pass through one-fourth of its orbit, it will be seen that as much of the globe is illuminated above the equator as there is beneath; consequently, the day and night must be equal. Passing on towards the winter season, we find the south pole of the Earth presented towards the Sun, and as Great Britain is situated North of the equator, our nights must then be longer than the day; this, then, is our winter season.

Thus we see the reason why the days lengthen and shorten from the equator to the polar circles every year; why there is periodically no day or night for many turnings of the earth within the polar circles; why there is but one day and one night in the whole year at the poles; and why the days and nights are equally long all the year round at the equator, which is equally cut by the circle bounding light and darkness. The inclination of an axis, or of the plane of an orbit, is merely relative, arising out of the comparison we make with some other axis or orbit, which we do not consider as inclined at all.

Though we say that the inhabitants within the arctic and antarctic circles are at opposite times of the year deprived of the sight of the sun, yet they are not altogether deprived of his light; for the atmosphere reflecting and refracting the sun's light, forms a twilight at the distance of even eighteen degrees. Hence, the day breaks to us when the sun is still eighteen degrees below the eastern horizon; and we have his light in the evening till he sinks eighteen degrees below the western. But as the sun in summer rises considerably to the north of the east, and sets also to the north of the west with us, he rises and sets very obliquely to the horizon, and the twilight is of long duration. At Midsummer, Great Britain has no night, for the whole island is within eighteen degrees of the horizon, or boundary of the sun's light. In high southern latitudes, they enjoy in their turn the same advantage; but at the equator, the sun sinks abruptly from the horizon, because his path is at right angles to it, or very nearly so; and the quick transition from the glare of day to utter darkness, cuts off the enjoyment of the twilight hour.

Astronomers, however, usually commence the year in the spring, when the sun is in that node of the equator, or equinoctial point, at which the days begin to lengthen in the northern hemisphere. Now it is plain that if the equinoctial points had no motion, the earth would complete one revolution in its orbit in the same time that the sun employs in apparently passing from one of the equinoxes, and returning again to the same. But as there is a retrograde motion, the line of the nodes of the equator, or diameter of the earth which joins the equinoctial points, is brought to coincide again with the line which joins the centres of the sun and earth, before its periodical revolution is completed; and therefore the circle of the seasons is performed in less time than the earth's revolution in its orbit. The actions both of the sun and moon on the redundant matter in the equatorial regions, tend to produce this motion, which is so slow, that a complete revolution will not be finished in less than twenty-five thousand years. This is called the precession of the equinoxes, and is the reason that the fixed stars appear to advance in longitude about fifty seconds of time in a year: whence it has happened, that, since the time of Ptolemy, the zodiacal figures have advanced the greater part of a whole sign: the constellation Aries being situated in that part of the ecliptic which is denominated from Taurus; Taurus in the place of Gemini, &c. The difference between the natural year, or period of the seasons, and the periodical year, or time of the earth's revolution in its orbit, has already been fully examined when treating of the sun and earth.

The sidereal year, or time employed by the sun in returning to the same apparent position with respect to a fixed star, is $365^{d}.6^{h}.9'.9''$. The difference between the periodical and sidereal year is occasioned by the motion of the apsis of the earth's orbit.

The motion of the *moon*, or satellite that attends on our planet, must next be examined, as its phases depend on a continual change of place.

Although the moon, in reality, revolves about the common centre of gravity between itself and the earth, and not about the earth itself, and consequently their motions and irregularities are similar, and not confined to the moon alone; yet it may be easily conceived, that the conclusions with reference to the latter body, are not affected in any degree that may be here regarded, when, for the sake of conciseness, we suppose one of the two bodies to be quiescent, and the other to revolve about it.

When the moon is visible in the day-time, its light is so nearly equal to that of the lighter thin clouds, that it is with difficulty distinguished amongst them. Its light continues the same during the night; but the absence of the sun, suffering the aperture or pupil of the eye to dilate itself, renders it more conspicuous. It therefore follows, that if every part of the sky were equally capable of reflecting light with the moon's disc, the light would be the same as if, in the day-time, it were covered with the thin clouds above-mentioned. We discern a variety of spots with the naked eye, which the imagination naturally supposes to be spacious seas, and continents; but on a more accurate inspection, with the assistance of a telescope, it is perceived that many of those appearances are occasioned by vast cavities, closely intersected by mountainous ridges. The heights of these mountains may easily be found; for by the horizontal parallax, we know that the earth's apparent diameter, seen from the moon at its mean distance, is 1°54′ (132, ×) or 6840 seconds; while that of the moon, seen from the earth at the same distance, is 31′29″, or 1889 seconds. Their absolute diameters must therefore be in proportion to these numbers. Consequently, if we find the proportion the height of a lunar mountain bears to the moon's diameter, we may, without difficulty, find the quantity of that height in miles, or other terrestrial dimensions.

These mountains and cavities are known to be such, from their shadows. In the first and second quarters, when the sun shines obliquely on the face of the moon, the elevated parts cast a triangular shadow in the direction from the sun; and, on the contrary, the cavities are dark on the side next the sun, and illuminated on the opposite side. The shadows shorten as the sun becomes more directly opposed to the anterior face of the moon, and at length disappear at the time of the full. During the third and last quarters, the shadows appear again, but all fall towards the contrary side of the moon, though still with the same distinction: namely, that the mountains are dark and shady on the side farthest from the sun, and the pits are dark on the side next the sun.

The most remarkable appearance in the moon, is the continual change of figure to which it is subject. Sometimes it appears perfectly full, or circular, at other times less than half-illuminated, changing through a very great variety of figures. These changes being always the same at the same elongation from the sun, are a proof that it receives its light from that luminary; for the moon is enlightened only on the side that faces the sun; and a greater or less quantity of that enlightened part is visible to us, according to our position. This cannot be better illustrated than by an ivory ball, which being held in the sun in various positions, will present a greater or less part of its illuminated side to the view of the observer. If it be held nearly in opposition, so that the eye of the observer may be almost immediately between it and the sun, the greatest part of the enlightened side will be seen. But if it be moved in a circular orbit towards the sun, the visible enlightened part will gradually decrease, and at last disappear when the ball is held directly towards the sun. Or, to apply the experiment more immediately to our present purpose, if the ball at any time, when the sun and moon are both visible, be held directly between the eye of the observer and the moon, that part of the ball on which the sun shines, will appear exactly of the same figure as the moon itself.

Since the earth, when beheld from the moon, must always appear in the part of the heavens immediately opposite the moon's apparent place, as seen from the earth, the enlightened side of the earth will have the same figure, when seen from the moon, as the dark side of the moon would exhibit if it could be seen at the same instant from the earth. Thus, when the moon is invisible, or near the conjunction, the earth is in opposition, and presents a full luminous face to the moon; and on the contrary, when the moon is at the full, or opposite the sun, it must be on the dark side of the earth, which consequently then becomes invisible.

When the earth, in turning on its axis from west to east, has revolved from one meridian to the same meridian again, the moon, which also revolves from west to east, has advanced over little more than a thirtieth part of her orbit, or 12° and some minutes: this is not, however, constantly the case, except at or near the equator; for on account of the different angles made by the horizon at di ferent parts of the moon's orbit, this retardation differs considerably in places of high latitude. Twice in the year she rises for a week together, nearly at the same time; and these phenomena happening successively in autumn, the earlier is called the *harvest moon*, and the latter the *hunter's moon*. We shall chiefly be indebted to Ferguson for the explanation of these problems.

The plane of the equinoctial is perpendicular to the earth's axis; and, therefore, as the earth turns round on its axis, all parts of the equinoctial make equal angles with the horizon, both at rising and at setting; so that equal portions of it always rise or set in equal times. Consequently, if the moon's motion were equable, and in the equinoctial, at the rate of 12°11′ from the sun every day, as it is in her orbit, she would rise and set fifty minutes later every day than on the preceding day: for 12°11′ of the equinoctial rise or set in 50′ of time in all latitudes. But the moon's orbit is so nearly in the same plane as the ecliptic, that we may consider her at present as moving in the ecliptic. Now the different parts of the ecliptic, on account of its obliquity to the earth's axis, make very different angles with the horizon as they rise or set. Those parts or signs which rise with the smallest angles, set with the greatest, and *vice versa*.

In northern latitudes, the smallest angle made by the ecliptic and horizon, is when Aries rises, at which time Libra sets; the greatest when Libra rises, at which time Aries sets. From the rising of Aries to the rising of Libra, (which is twelve siderial hours,) the angle increases; and from the rising of Libra to the rising of Aries, it decreases in the same proportion; hence it appears that the ecliptic rises fastest about Aries, and slowest about Libra.

On the parallel of London, as much of the ecliptic rises about Pisces and Aries in two hours, as the moon goes through in six days; therefore, whilst the moon is in these signs, she differs but two hours in rising for six days together, that is, about twenty minutes later every day or night than on the preceding, at a mean rate. But in fourteen days afterwards, the moon comes to Virgo and Libra, which are the opposite signs to Pisces and Aries: and then she differs almost four times as much in rising; namely, one hour and about 15′ later every day or night than the preceding, whilst she is in these signs. As the signs Taurus, Gemini, Cancer, Leo, Virgo, and Libra, rise successively, the angle of the ecliptic with the horizon increases gradually; and decreases in the same proportion as they set; and for that reason, the moon differs gradually more in the time of her rising, every day whilst she is in these signs, and less in her setting: after which, through the other six signs, viz. Scorpio, Sagittarius, Capricorn, Aquarius, Pisces, and Aries, the rising difference becomes less every day, until it arrive at the least of all; namely, in Pisces and Aries.

The moon goes round the ecliptic in about twenty-seven days and eight hours; but not from change to change in less than about twenty-nine days and a half, so that she is in Pisces and Aries at least once in every lunation, and all; in some lunations twice.

If the earth had no annual motion, the sun would never appear to shift its place in the ecliptic, and then every new moon would fall in the same sign and degree of the ecliptic, and every full moon in the opposite; for the moon would go precisely round the ecliptic from change to change. So that if the moon was once full in Pisces or Aries, she would always be full when she came round to the same sign and degree again. And as the full-moon rises at sun-set, (because, when any point of the ecliptic sets, the opposite point rises,) she would constantly rise within two hours of sun-set, on the parallel of London, during the week in which she was full. But during the time that the moon goes round the ecliptic from any conjunction or opposition, the earth goes almost a sign forward, and, therefore, the sun will seem to go as far forward in that time, namely, 27½°; so that the moon must go 27½° more than the round, and as much farther as the sun advances in that interval, which is $2\frac{1}{15}$°, before she can be in conjunction with, or opposite to the sun again. Hence it is evident, that there can be but one conjunction or opposition of the sun and moon in a year, in any particular part of the ecliptic. This may be familiarly exemplified by the hour and minute hands of a watch, which in twelve hours are never in conjunction or opposition in that part of the dial-plate where they were so last before.

As the moon can never be full but when she is opposite to the sun, and the sun is never in Virgo and Libra but in our autumnal months, it is plain that the moon is never full in the opposite signs, Pisces and Aries, but in these two months; and therefore we can only have two full moons in the year which rise nearly at the time of sun-set for a week together, as has been mentioned above.

When the moon is in Pisces and Aries, she must rise with nearly the same difference of time in every revolution through her orbit, which is exactly the phenomenon of the harvest-moon; but it passes unobserved, because in winter, those signs rise at noon, and being then only a quarter of a circle distant from the sun, and the moon in them is in her first quarter, and rises about noon, at which time her rising is not noticed. In spring, those signs rise with the sun, for the sun is in them; consequently, the moon being in them too, is in conjunction with the sun, and therefore her rising is invisible. In summer, those signs rise about midnight, and the sun is three signs, or about 90° before them, therefore, the moon in them must be in her third quarter, when she gives little light, and rises late, on which accounts, the phenomenon of her rising for some nights with little difference of time, passes unnoticed. In autumn, however, the case is different, for the signs of Pisces and Aries then rise about sun-set, and therefore the moon being in them, is in opposition to the sun, consequently full, and rises in great splendour when the sun sets, and seems to prolong the day, for the advantage of the husbandman at the time of harvest.

In northern latitudes, the autumnal full-moons are in Pisces and Aries; and the vernal full-moons in Virgo and Libra. In southern latitudes, just the reverse, because the seasons are contrary. But Virgo and Libra rise at as small angles with the horizon in southern latitudes, as Pisces and Aries do in the northern; and therefore the harvest-moons are just as regular on one side of the equator as on the other.

As those signs which rise with the least angle, set with the greatest, the vernal full-moons differ as much in their times of rising every night, as the autumnal full-moons differ in their times of setting; and set with as little difference as the autumnal full-moons rise; the one being in all cases the reverse of the other.

Hitherto, to avoid the complication of the subject, the moon's orbit has been supposed to coincide with the ecliptic; but since her orbit makes an angle with the ecliptic, varying from 5° to 5°18′, one half of it is on one side of the ecliptic, and the other on the other side, and she only coincides with it when at the points of intersection, called her nodes, which coincidence cannot happen less than twice, but sometimes happens thrice, between change and change. For as the moon goes almost a whole sign more than round her orbit from change to change, if she passes through either node at, or a little before the time of change, she will pass by the other about fourteen days afterwards, and come round to the former node before the next change. When the motion is northward of the ecliptic, she rises sooner and sets later than if she moved in the ecliptic; and when she is southward of the ecliptic, she rises later and sets sooner. This difference is variable, even in the same signs, because the nodes shift backwards about 19° in the ecliptic every year, and so go round it, contrary to the order of the signs, in eighteen years two hundred and twenty-eight days.

When the ascending node is in Aries, the southern half of the moon's orbit makes an angle of 5⅓° less with the horizon than the ecliptic does when Aries rises in northern latitudes; for which reason, the moon rises with less difference of time when she is in Pisces and Aries, than if she moved in the ecliptic, and will differ only one hour and forty minutes for the whole of seven days. But in nine years one hundred and fourteen days afterwards, the descending node comes to Aries, and then the moon's orbit makes an angle of 5⅓° greater with the horizon when Aries rises, than the ecliptic does at that time; which causes the moon to rise with greater difference of time in Pisces and Aries, than if she moved in the ecliptic; this difference, in the course of a week, will amount to full three hours and a half. Hence, though we observe the phenomenon of the harvest-moon every year, yet it is not every year equally remarkable, but alternately, for a period of nearly nine years and a half, it is greatest and least; from 1813 to 1815 is the remainder of a period during which the harvest-moon varies most in the time of rising; from 1816 to 1825, includes a period during which the difference is the least.

The principal phenomena of the *tides*, in which the moon is so material an agent, may be thus illustrated.

1. The sea is observed to flow for about six hours from south to north, gradually swelling; after this it seems to rest for a quarter of an hour, and then to ebb, or retire back again from north to south, for six hours more. Then after another pause of about a quarter of an hour, the sea again begins to flow; and so on alternately.

2. The time of a flux and reflux is, on an average, about twelve hours and twenty-five minutes, and twice this time, or twenty-hours and fifty minutes, is the period of a lunar day, or the time between the moon's passing a meridian, and coming to the same point of it again. So that the sea flows as often as the moon passes the meridian, that is, as well when she comes to the arch above the horizon, as when she comes to that below the horizon; and ebbs as often as the moon passes the horizon, both on the eastern and western side.

3. The elevation of the waters on that side of the earth immediately under the moon, somewhat exceeds the elevation of the opposite side, and in all cases the elevation diminishes from the equator to the poles.

4. The sun raises and depresses the sea twice every day, in the same manner as the moon; but the solar influence in this respect is less than that of the moon, in the proportion of 1 to 3.

5. The tides which depend on the actions of the sun and

moon, are not distinguished, but compounded; and thus they form, to appearance, one united tide, which, increasing and decreasing, produces *neap* and *spring* tides.

6. In the syzygies, that is, when the moon is either new or full, the action of both luminaries concur, and the tides are highest; but they are least in the quadratures, or when the lines of their action are ninety degrees apart; for where the water is elevated by the moon, it is depressed by the sun, and *vice versa*. Therefore, while the moon passes from the syzygy to the quadrature, the daily elevations are continually diminished; on the contrary, they are increased, while the moon passes from the quadrature to the syzygy. At the new moon, also, the tides are the greatest, because the sun and moon are not only in the same line, but on the same side of the earth; and at this time the tides of the same day are more different than those at full-moon.

7. The greatest elevations and depressions take place on the second or third day after the new and full moon; and they are the greater, the nearer the luminaries are to the plane of the equator; they are therefore greatest in the syzygies at the time of the equinoxes.

8. The actions of the sun and moon are greater, the nearer these bodies are to the earth; and the greatest tides happen when the sun is a little to the south of the equator; but this does not happen regularly every year, because some variation may arise from the situation of the moon's orbit, and the distance of the syzygy from the equinox.

9. As the mean force of the moon to move the sea, is to that of the sun nearly as 3 to 1; if the action of the sun alone would produce a tide of two feet, which it is said to do, then that of the moon will be six feet; hence, the

spring-tides will be eight feet, and the neap-tides four feet.

We have seen that the waters of the ocean must rise at the same time at that part of the ocean which is immediately under the moon, and at the opposite point. Consequently, at ninety degrees from these points on each side, the water must be lowered. In the same manner, the solar action must elevate the waters in that part which is immediately under the sun, and at the part diametrically opposite. Combining the two actions, we shall find that the elevation of the water at the same place must be subject to some variations, both with respect to quantity and time, according as the solar and lunar actions are combined, or according as these forces act differently, or against each other. In general, in conjunctions and oppositions of the sun and moon, their forces are combined. In conjunctions, these bodies act on the same meridian; and in opposition, they still act in the same line, and each raises the water on that side which is immediately under it. In the quadratures, on the contrary, the water which is elevated by the sun, is depressed by the moon's attraction, for the moon is then ninety degrees from the sun. This, then, is the time of the lowest, or neap-tides; and the highest, or spring-tides, happen at new and full moon, when the two luminaries are in conjunction, or opposition. In the course of every day there are two tides, which depend upon the action of the sun, as in every lunar day there are two, which depend on that of the moon; all follow, however, the same laws. The effect of the sun, as has been stated, is, however, much feebler than that of the moon; as the mass of the sun is much greater than that of the earth and the moon together, yet its immense distance lessens its force most materially.

In general, the nearer the moon happens to be to the earth, the greater is its attraction; and the same may be said of the sun. Laying aside, for the present, the action of the sun on the ocean, the highest tide would be at the moment when the moon passed the meridian, if the waters had not, like all other bodies in motion, a *vis inertiæ*, by which they are inclined to retain the impression they have received. But this force must necessarily produce two effects. It must retard the time of high water, and it must in general diminish the height of the tide. As a proof, let us for a moment suppose the earth at rest, and the moon above it in a certain point. Abstracting, then, the action of the sun, the force of which upon the tides is much less than that of the moon, the water would unquestionably rise in that part which was under the moon. Let us suppose again that the earth turns upon its axis, on one side it turns very rapidly as to the motion of the moon; and on the other, the water which has been raised by the moon, and which turns with the earth, endeavours (if we may use the expression) to preserve by its *vis inertiæ*, the elevation which it has acquired, though in withdrawing from the moon, it loses somewhat of that elevation. Thus, the water carried forward by the motion of the earth on its axis, will be elevated more to the east of the moon than it would have been without this motion; yet it will at the same time be less elevated than it would have been directly under the moon, had the earth continued immovable. The motion of the earth on its own axis, then, has in general a tendency to retard the time of high water, and to lessen its elevation. Both after the flux and reflux, the ocean continues some time quiescent, neither disposed to rise or fall;

because the waters have a tendency to preserve the state of rest and equilibrium in which they are at the flood and ebb tide; and because the motion of the earth, displacing the waters with relation to the moon, lessens the intensity of the action of that luminary. These two efforts counterbalance each other for some moments. We must add also, that the attraction of the particles of the fluid to each other, and obstacles of different kinds, which must retard their motion, prevent them from passing all at once from the tide of flood to that of ebb. The moon passes above the eastern parts of the globe before the western. The flood-tide, therefore, always proceeds in this direction.

From the lightness of the air, its freedom of motion, and its greater nearness to the moon than the ocean, it may be supposed that there are aërial tides of great elevation; but experience seems to contradict this supposition when we find that there are no changes of the barometer satisfactorily indicating this to be the case. A little consideration, however, will show, that such a change of the barometer is not to be expected. By the preceding theory of the tides, it appears that water is higher immediately under the moon, and at the same time to the antipodes of the point immediately under her, that is, at those two places on the earth where her attraction is greatest and least. Now, though the water is higher at these two points than elsewhere, yet it does not follow that the water, from its increased quantity, presses with a proportionably greater weight on the bottom of the ocean than before it was thus raised up, because the moon's attraction has diminished that tendency to the centre of the earth, which constitutes the weight of bodies. Hence we may suppose, that though the moon draws up the atmosphere to a great height, yet a higher column of mercury is not supported through this circumstance, because the actual weight of the atmosphere remains but little affected.

The motion of the planetary bodies by intercepting the sun's rays, occasionally produces an eclipse of that luminary.*

With reference to the phenomena of *eclipses*, it may be observed that new moon is that situation of the earth's satellite, in which it has exactly the same longitude as the sun. This phase may take place at any part of the lunar orbit, either in the nodes, or any distance from them. In the first case, she will appear to pass over the disc of the sun; but if at the conjunction, or time of the new moon, she should be at some distance from the node, as is usually the case, she will be invisible to us; but were she visible at this time, we should see her directly over, or under the sun; and the distance would be the greater, the farther the moon was from the node: but this distance never could much exceed 5°, or the angle expressing the inclination of the two orbits.

Full moon is that position of the moon when her longitude differs exactly half a circle from that of the sun; that is, its longitude is the same as the longitude of the centre of the earth's shadow, if we suppose it extended till it meet the ecliptic. This phase of the moon may take place likewise in any part of her orbit; she may therefore be above, below, or in the centre of the earth's shadow; in which latter case, being deprived of the light of the sun, by the interposition of the earth, she will be eclipsed.

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* The words *transit, occultation,* and *eclipse,* are all employed to designate the same general phenomenon, of one heavenly body being lost sight of, either wholly or in part, by the interposition of another; but they are not used indiscriminately. The word *transit* denotes the passage of the inferior planets, Venus and Mercury, over the sun's disc; *occultation*, the disappearance of the stars or planets by the interposition of the moon; and *eclipse,* 1st, to the obscuration of the moon, when this luminary falls into the earth's shadow, called an *eclipse of the moon;* 2nd, to the obscuration of the sun, when the earth falls into the moon's shadow, called an *eclipse of the sun;* and 3d, to the obscuration of the satellites of any of the planets, by their coming within the shadows of their respective primaries. One of the two first of these three phenomena is always meant when the word eclipse is used alone.

When the moon passes the conjunction, or becomes new, near to the node, she eclipses the sun, and when she is full, or in opposition, in similar circumstances, she herself enters the earth's shabow. The earth's shadow consists of two parts; the true shadow, within which none of the sun's surface is visible, and the penumbra, which is deprived of a part only of the sun's light; the true shadow forms a cone terminating in a point, at a little more than 3¼ times the mean distance of the moon; the penumbra, on the contrary, constitutes, together with the shadow, a portion of a cone diverging from the earth without limit; but the only effect of this imperfect shadow is, that it causes the beginning of a lunar eclipse to be incapable of very precise determination; for the limit of the darkened part of the moon, as it appears in the progress of the eclipse, is that of the true shadow, very little enlarged by the penumbra. The true shadow, where the moon crosses it, is about 80 minutes in diameter, as seen from the earth, while the moon herself is only 30. This shadow is not, however, wholly deprived of the sun's light; for the atmospheric refraction inflects the light passing nearest to the earth, in an angle of 66 minutes, and causes a great part of the shadow to be filled with light of a ruddy hue, by means of which the moon remains still visible to us, the cone of total darkness extending to somewhat less than two-thirds of the moon's distance. But it has sometimes happened, probably from the effects of clouds occupying the greatest part of our atmosphere, that the moon has totally disappeared.

When the sun is eclipsed, it depends on the situation of the earth and moon in their orbits, whether the sun or moon subtends the greatest angle as seen from the earth; since at their mean distances, their apparent diameters are each about half a degree. If the sun's apparent diameter is the greater, the eclipse, when the centres coincide, must be annular, the margin of the sun's disc being still visible in the form of a ring: when the moon's apparent diameter is greater than the sun's, the eclipse, if central, becomes total; but still a ring of pale light is seen round the disc, which has been attributed to the effect of the sun's atmosphere, since that of the moon is probably too inconsiderable to produce the appearance: a red streak is also *sometimes* observed at the margin, before the actual emersion of the sun. The degree of darkness depends on the situation of the place of observation within the shadow, on account of the greater or less illumination of the atmosphere within view: sometimes a considerable number of stars may be seen during a total eclipse of the sun.

To complete the above view of the solar system, it will be necessary now to examine another class of bodies, differing very considerably in their arrangement from the planets. These are the *comets:* they generally appear attended by a nebulous light, either surrounding them as a comma, or stretched out to a considerable length as a tail; and they sometimes seem to consist of such light only. Their orbits are so eccentric, that in their remoter situations, the comets are no longer visible to us, although at other times they approach much nearer to the sun than any of the planets: for the comet of 1680, when in its perihelion, was at the distance of only one-sixth of the sun's diameter from its surface. Their tails are often of great extent, appearing as a faint light, directed always towards a point nearly opposite to the sun: it is quite uncertain of what substance they consist; and it is difficult to determine which of the conjectures respecting them can be considered as the least improbable: it is possible that, on account of the intense cold to which the comets are subjected in the greatest part of their revolutions, some substances, more light than any thing we can imagine on the earth, may be retained by them in a liquid, or even in a solid form, until they are disengaged by the effect of the sun's heat. But we are still equally at a loss to explain the rapidity of their ascent; for the buoyancy of the sun's atmosphere cannot possibly be supposed to be adequate to the effect; and on the whole, there is, perhaps, reason to believe that the appearances are derived from some cause, bearing a considerable analogy to the fluid supposed to be concerned in the effects of electricity. It is probable that the density of the nucleus, or the body of the comet itself, is comparatively small, and its attraction for the tail consequently weak, so that it has little tendency to reduce the tail, even if it consists of a material substance, to a spherical form; for since some comets have no visible nucleus at all, there is no difficulty in supposing the nucleus, when present, to be of a very moderate density, and perhaps to consist of the same kind of substance as constitutes the tail, or comma, in a state of somewhat greater condensation. If, therefore, it should ever happen to a planet to fall exactly in the way of a comet, of which there is but very little probability, it is to be supposed that the inconvenience suffered by the inhabitants of the planet might be merely temporary and local: the chances are, however, much greater, that a comet might interfere in such a manner with a planet, as to deflect it a little from its course, and retire again without coming actually into contact with it.

The number of comets is very much greater than that of the planets which move in the vicinity of the sun. From the reports of former historians, as well as from the observations of late years, it is ascertained that more than four hundred and fifty have been seen previous to the year 1771; and when the attention of astronomers was called to this subject, by the expectation of the return of the comet of 1759, no fewer than seven were observed in the course of as many years. From this circumstance, and the probability that all the comets recorded in ancient authors, were of considerable apparent magnitude, while the smaller were overlooked; it is reasonable to conclude that the number of comets is considerably beyond any estimation that might be made from the observations we now possess. But the number of comets whose orbits are settled with sufficient accuracy to ascertain their identity when they may appear again, is no more than fifty-nine, reckoning as late as the year 1771. The orbits of most of these are inclined to the plane of the ecliptic in large angles, and the greater number of them approached nearer the sun than the earth ever does. Their motions in the heavens are not at all in the order of the signs, or direct, like those of the planets; but the number whose motion is retrograde, is nearly equal to that of those whose motion is direct.

The analogy between the periodical time of the planets, and their distances from the sun, discovered by Kepler, takes place also in the comets. Hence, the mean distance of a comet from the sun may be found by comparing its period with the time of the earth's revolution round the sun: thus, the period of the comet that appeared in 1531, 1607, 1682, and 1759, being about seventy-six years, its mean distance is found by this proportion: as the square of one year, the earth's periodical time, is to 5776 the square of 76, the comet's periodical time; so is 1,000,000 the cube of 100, the earth's mean distance from the sun, to 5,776,000,000 the cube of the comet's mean distance, the cube root of which is 1794, the mean distance itself, in such parts as the mean distance of the earth contains 100. If the perihelion distance of this comet, 58, be taken from 3588, double the mean distance, we shall have the aphelion distance 3530 of such parts as the distance of the earth contains 100; and this is little more than 35 times the distance of the earth from the sun. By a like method, the aphelion distance of the comet of 1680, comes out 138 times the mean distance of the earth from the sun, supposing its period to be 575 years; so that this comet in its aphelion, goes to more than 14 times the distance from the sun that Saturn does.

Comets, in describing their elliptic orbits round the sun, have been found to be disturbed by the action of the larger planets, Jupiter and Saturn; but the great eccentricity of their orbits makes it impossible, in the present state of mathematical science, to assign the quantity of that disturbance for an indefinite number of revolutions, though it may be done for a limited portion of time, by considering the orbit as an ellipsis the elements of which are continually changing. This method was suggested by La Grange, and is followed in the Mécanique Céleste. Dr. Halley, when he predicted the return of the comet of 1682, took into consideration the action of Jupiter, and concluded that it would increase the periodic time of the comet a little more than a year; he therefore fixed the time of the reappearance to the end of the year 1758, or the beginning of 1759. He professed, however, to have made this calculation hastily, or, as he expresses it, *levi calamo.*—(Synopsis of the Astronomy of Comets.)

The effects both of Jupiter and Saturn, on the return of the same comet, were afterwards calculated more accurately by Clairaut, who found that it would be retarded 511 days by the action of the former planet, and 100 by the action of the latter; in consequence of which, the return of the comet to its perihelion would be on the 15th of April, 1759. He admitted, at the same time, that he might be out a month in his calculation. The comet actually reached its perihelion on the 13th of March, just thirty-three days earlier than was predicted; affording, in this way, a very striking verification of the theory of gravity, and the calculation of disturbing forces. The same comet may be expected again about the year 1835.

In some instances, the effects which the planets produce on the motion of comets, are far more considerable than in this example. A comet which was observed in 1770, had a motion which could not be reconciled to a parabolic orbit; but which could be represented by an elliptic orbit of no great eccentricity, in which it revolved in the space of five years and eight months. This comet, however, which had never been seen in any former revolution, has not been seen in any subsequent one. On tracing the path of this comet, Mr. Burkhardt found that, between the years 1767 and 1770, it had come very near to Jupiter, and had done so again in 1779. He therefore conjectured, that the action of Jupiter may have so altered the original orbit, as to render the comet for a time visible from the earth; and that the same cause may have so changed it, after one revolution, as to restore the comet to the same region in which it had formerly moved. This, if a true conjecture, is the greatest instance of disturbance which has yet been discovered among the bodies of our system, and furnishes a very happy as well as an unexpected confirmation of the theory of gravity.

Though the comets are so much disturbed by the action of the planets, yet it does not appear that their re-action produces any sensible effect. The comet of 1770 came so near to the earth as to have its periodical return accelerated by two days; two hundred and forty-six, according to La Place; and if it had been equal in mass to the earth, it would have augmented the length of the year by not less than two hours and forty-eight minutes. It is certain that no such augmentation took place, and therefore that the disturbing force by which the comet diminished the gravity of the earth is insensible, and the mass of the comet, therefore, less than 1-500th of the mass of the earth. The same comet also passed through the middle of the satellites of Jupiter. Hence, it is reasonable to conclude, that no material, or even sensible alteration, has ever been produced in our system by the action of a comet.

M. Fatio has suggested that some of the comets have their nodes so very near the annual orbit of the earth, that if the earth should happen to be found in that part next the node, at the time of a comet's passing by, as the apparent motion of the comet will be incredibly swift, so its parallax will become very sensible; and the proportion thereof to that of the sun will be given; whence such transits of comets will afford the best means of determining the distance of the earth and sun.

The comet of 1472 had a parallax above twenty times greater than the sun's: and if that of 1618 had come down in the beginning of March to its descending node, it would have been much nearer the earth, and its parallax much more obvious. But, hitherto, none has threatened the earth with a nearer approach than that of 1680; for, by calculation, Dr. Halley found that on the 11th of November, that comet was not above one semi-diameter from the earth, to the northward of the earth's path; at which time, had the earth been in that part of its orbit, the comet would have had a parallax equal to that of the moon.

If the earth had been at this time in that part of her orbit nearest to that node of the comet, through which it passed, their mutual gravitation must have caused a change in the plane of the orbit of the earth, and in the length of our year. Dr. Halley adds, that if so large a body, with so rapid a motion as that of this comet near its perihelion, were to strike against our earth, the shock might reduce this beautiful frame to its original chaos.

It would be a waste of time to detail the various wild and extravagant opinions which have been entertained respecting these interesting bodies. During the ages of barbarism and superstition, they were regarded as the harbingers of awful convulsions, both in the political and in the physical world. Wars, pestilence, and famine, the dethronement of kings, the fall of nations, and the more alarming convulsions of the globe, were the dreadful evils which they presented to the diseased and terrified imaginations of men. As the light of knowledge dissipated these gloomy apprehensions, the absurdities of vague speculation supplied their place, and all the ingenuity of conjecture was exhausted in assigning some rational office to these wandering planets. Even at the beginning of the eighteenth century, the friend and companion of Newton regarded them as the abode of the damned. Anxious to know more than what is revealed, the fancy of speculative theologians strove to discover the frightful regions in which vice was to suffer its merited punishment; and the interior caverns of the earth had, in general been regarded as the awful prison-house in which the Almighty was to dispense the severities of justice. Mr. Whiston, however, outstripped all his predecessors in fertility of invention. He pretended, not only to fix the residence of the damned, but also the nature of their punishment. Wheeled from the remotest limits of the system, the chilling regions of darkness and cold, the comet wafted them into the very vicinity of the sun; and thus alternately hurried its wretched tenants to the terrifying extremes of intolerable cold and devouring fire.

By other astronomers, comets were destined for more scientific purposes. They were supposed to convey back to the planets, the electric fluid which is constantly dissipating, or to supply the sun with the fuel which it perpetually consumes. They have been regarded, also, as the cause of the deluge. The transient effect of a comet passing near the earth, could scarcely amount to any great convulsion; but if the earth were really to receive a shock from one of these bodies, the consequences, as La Place has shown, would be awful. A new direction would be given to its rotatory motion, and the globe would revolve round a new axis. The seas, forsaking their ancient beds, would be hurried by their centrifugal force to the new equatorial regions; islands and continents, the abode of men and animals, would be covered with the universal rush of the waters to the new equator, and every vestige of human industry and genius at once destroyed.

Proceeding onward, to the more distant regions of space, we come to the *fixed stars.* Prior to a notice of their classification, however, a few preliminary remarks will best explain their nature and arrangement.

The fixed stars are farther distant from the earth than the farthest of the planets; as we frequently find the fixed stars hid behind the most distant of those bodies; and they are supposed to have no parallax, which the planets have. It is inferred that the fixed stars are greater than our earth; for if that was not the case, they could not be visible at such an immense distance.

It is evident also, that the fixed stars shine with their own light; for they are much farther from the sun than the remotest planet, and appear much smaller; but since, notwithstanding this, they are found to shine much brighter than such planet, it is evident they cannot borrow their light from the same source.

Astronomers divide the heavens into three regions; a northern and a southern hemisphere, and the zodiac. Stars of various magnitudes are seen in all these regions, and are classed into what are called constellations, or systems of stars, according as they lie near one another, so as to occupy those spaces which the figures of different sorts of animals would take up, if they were delineated on what appears to be the concave surface of the heavens. Those stars which the ancients could not bring into any particular constellation, they called unformed stars, but most of these are comprehended in the new constellations of the moderns.

This mode of dividing the stars into different constellations, serves to arrange them in such a manner that any particular star may be readily found in the heavens by means of a celestial globe, on which the constellations are so delineated as to put the most remarkable stars into those parts of the figures, which may be most easily pointed out. This may be illustrated by a reference to the classification already alluded to.

CONSTELLATIONS OF THE ZODIAC.

Constellations.	No. of Stars.	Principal stars and their magnitudes.	
Aries	66		
Taurus	140	Aldebaran	1
Gemini	85	Castor 1, Pollux	2
Cancer	83		
Leo	95	Regulus	1
Virgo	110	Spica Virginis	1
Libra	51	Zubenich Meli	2
Scorpio	44	Antares	1
Sagittarius	69		
Capricornus	51		
Aquarius	108	Scheat	3
Pisces	112		

CONSTELLATIONS ON THE NORTH SIDE OF THE ZODIAC.

Ursa Minor	24	Stella Polous	2
Ursa Major	87	Dubhe	1
Cassiopeia	55		
Perseus	59	Algenib	2
Auriga	56	Capella	1
Bootes	54	Arcturus	1
Draco	60	Rastaben	2
Cepheus	35	Alderamin	3
Canes Venatici, viz. Asterion and Chara	25		
Cor Caroli	3		
Triangulum	16		
Triangulum Minus	5		
Musca	6		
Lynx	44		
Leo Minor	24		
Coma Berenicis	40		
Camelopardalus	58		
Mons Mœnalus	11		

Constellations.	No. of Stars.	Principal stars and their magnitudes.	
Corona Borealis	21		
Serpens	50		
Scutum Sobieski	8		
Hercules, cum Ramo et Cerbero	113	Ras Algethi	3
Serpentarius sive Ophuichus	67	Ras Alhagus	2
Taurus Poniatowski	7		
Lyra	22	Vega	1
Vulpecula et Anser	37		
Sagitta	18		
Aquila	40	Altair	1
Delphinus	18		
Cygnus	73	Deneb Adige	1
Equulus	10		
Lacerta	16		
Pegasus	85	Markab	2
Andromeda	66	Almaach	2

CONSTELLATIONS ON THE SOUTH SIDE OF THE ZODIAC.

Phœnix	13		
Officina sculptoria	12		
Eridanus	76	Acherner	1
Hydrus	10		
Cetus.	80	Menekar	2
Fornax Chemica	14		
Horologium	12		
Reticulus Rhomboidalis	10		
Xiphias	7		
Cela Praxitelis	16		
Lepus	19		
Columba Noachi	10		
Orion	78	Betelgeux	1
Argo Navis	50	Canopus	1
Canis Major	30	Sirius	1
Equuleus Pictorius	8		
Monoceros	31		
Canis Minor	14	Procyon	1
Chamaeleon	10		

Constellations.	No. of Stars.	Principal stars and their magnitudes.	
Pyxis Nautica	4		
Piscis Volans	8		
Hydra	60	Cor Hydræ	1
Sextans	4		
Robur Carolinum	12		
Machina Pneumatica	3		
Crater	11	Alkes	3
Corvus	9	Algorab	3
Crux	6	Crucis	1
Musca	4		
Apus	11		
Circinus	4		
Centaurus	36		
Lupus	24		
Quadra Euclidis	12		
Triangulum Australe	5		
Ara	9		
Telescopium	9		
Corona Australis	12		
Pavo	14		
Indus	12		
Microscopium	10		
Octans Hadleianus	43		
Grus	14		
Toucan	9		
Piscis Australis	20	Tomachaut	

The stars vary very materially in their apparent magnitude and number at different periods of time.

The first new star that we have any good account of, was discovered by Cornelius Gemma, in 1572, in the chair of Cassiopeia. It surpassed Sirius in brightness and magnitude; and was seen for sixteen months successively. At first, it appeared larger than Jupiter, and then it gradually diminished both in magnitude and lustre, until 1573, when it became invisible.

On the 13th of August, 1596, David Fabricius observed the Stella Mira, in the neck of the whale; which has since appeared and disappeared periodically.

In the year 1600, William Janscnius discovered a changeable star in the neck of the swan; which, in time, became so small as to be thought to disappear entirely; till the year 1657, when it recovered its former lustre and magnitude.

In the year 1604, Kepler and several of his friends saw a new star near the heel of the right foot of Serpentarius, so bright, that it exceeded any thing they had ever seen before; and they state, that it was every moment changing into some of the colours of the rainbow, except when it was near the horizon, at which time it was generally white. It surpassed Jupiter in magnitude. It disappeared between October 1605, and the February following, and has not been seen since that time.

In July 1670, Hevelius discovered a new star, which was scarcely perceptible in October. In April following, it still retained its lustre, but wholly disappeared in August. In March 1672, it was seen again, but very small; and has not been visible since. It may be proper to add, that the star Algol, in the space of rather more than two days, changes from the second to the fourth magnitude.

M. Maupertuis, in his Dissertation on the Figures of the Celestial Bodies, is of opinion, that some stars, by their prodigious swift rotation on their axes, may not only assume the figures of oblate spheroids, but that by the great centrifugal force arising from such rotations, they may ultimately attain the figure of a mill-stone, or be reduced to flat circular planes, so thin, as to be quite invisible when their edges are turned towards us, as Saturn's ring is in such a position. But when very eccentric planets, or comets, go round any flat star in orbits much inclined to its equator, the attraction of the planets, or comets, in their perihelions must alter the inclination of the axes of the star; on which account it will appear more or less large and luminous, as its broad side is more or less towards us. And thus he imagines we may account for the apparent changes of magnitude and lustre of those stars, and likewise for their appearing and disappearing.*

Dr. Herschel's success in examining the milky-way, induced him to turn his telescope to the nebulous parts of the heavens. Most of these yielded to a Newtonian reflector, of twenty feet focal distance, and twelve inches aperture; and he ascertained that they were composed of stars, or at least contained stars, and afforded very strong indications of their consisting of them entirely. "The nebulæ," says he, "are arranged into strata, and run on to a great length, and some of them I have been able to pursue, and to guess pretty well at their form and direction. It is probable enough that they may surround the whole starry sphere of the heavens, not unlike the milky-way, which undoubtedly is nothing but a stratum of fixed stars; and as this immense starry bed is not of equal lustre in every part, nor runs in one straight direction, but is curved, and even divided into two streams along a very considerable portion of it; we may likewise expect the greatest variety in the strata of the cluster of the stars and nebulæ. One of these nebulous beds is so rich, that, in passing through a section of it in the time of only thirty-six minutes, I have detected no less than thirty-one nebulæ, all distinctly visible upon a fine blue sky. Their situation and shape, as well as condition, seem to denote the greatest variety imaginable. In another stratum, or perhaps a different branch of the former, I have often seen double and treble nebulæ variously arranged; large ones, with small seeming attendants; narrow, but much extended lucid nebulæ, or bright dashes; some of the shape of a fan, resembling an electric brush issuing from a lucid point; others of the cometic shape, with a seeming nucleus in the centre, or like cloudy stars, surrounded with a nebulous atmosphere; a different sort of orb again, containing a nebulosity of the milky kind, like that wonderful, inexplicable phenomena about Orionis; while others shine with a fainter mottled kind of light, which denotes their being resolvable into stars."

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* Hevelius apprehends, that the sun and stars are surrounded with atmospheres, and that, whirling round their axes with great rapidity, they throw off great quantities of matter into those atmospheres; and thus, he adds, it may happen that a star, which, when its atmosphere is clear, shines out with great lustre, may at another time, when it is full of clouds and thick vapours, appear greatly diminished in brightness and magnitude, or even become quite invisible.

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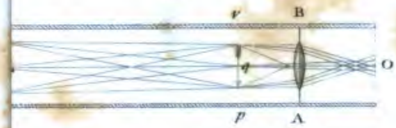

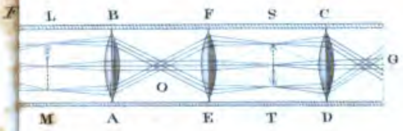

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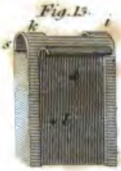

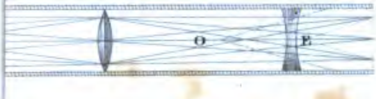

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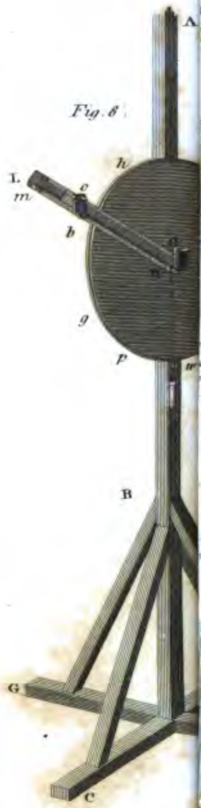

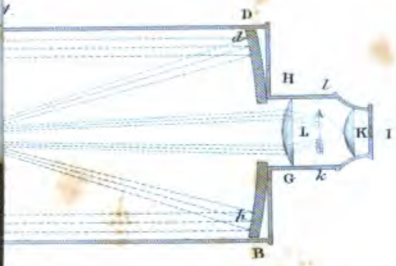

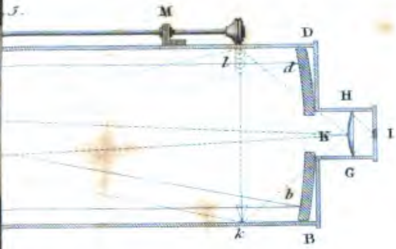

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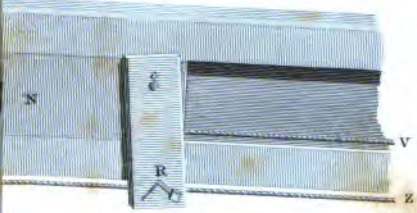

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